THE STEAM ENGINE

AND

ITS INVENTORS;

A Historical Sketch.

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London:

MACMILLAN AND CO.

1881.

LONDON:
R. CLAY, SONS, AND TAYLOR,
BREAD STREET HILL.

PREFACE.

As the following sketch of the history of the Steam Engine is on a somewhat different plan from most of the treatises on the same subject which have preceded it, a few words of explanation in reference to the course pursued may be desirable. No attempt is made to give an account of all the machines in which steam has been employed. The sole object aimed at is to exhibit the successive steps in the development of the cylinder and piston engine, which is the great prime mover of modern times. This engine was not originally a *steam* engine; it passed through several phases of existence in which steam gradually came to perform a more and more important part. It was not the invention of one individual, nor of one nation, nor of one age. Its growth has been a gradual and slow process; important modifications of its mechanism have been effected from time to time. No fact,

however, appears to be more certain than that the invention is entirely a modern one—that it originated in the discoveries of modern philosophy—and that it is in truth "one of the noblest gifts that *science* ever made to mankind."

It has not therefore been considered necessary to follow the usual course of beginning the narrative with an account of the steam "Æolipiles" of Hero the Alexandrian, who flourished about 250 B.C., nor to describe the projects of De Caus, Branca, Ramsey, and the Marquis of Worcester, but to proceed at once to those scientific discoveries of the seventeenth century, among which we must seek for the origin of the Steam Engine of the present day.

In preparing the following account great care has been taken to present reliable information. Wherever possible the materials have been drawn from the original sources. Copious references to authorities have been given, in order that the reader may be able to examine the foundation, so to speak, of the views put forward, the desire of the writer being to promote an impartial and truthful knowledge of the subject.

RYTON-ON-TYNE, *March* 16*th*, 1880.

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THE STEAM ENGINE

AND ITS INVENTORS.

CHAPTER I.

DISCOVERY OF THE TRUE NATURE OF THE VACUUM.—EXPERIMENTS IN CONNECTION WITH THE WEIGHT AND PRESSURE OF THE ATMOSPHERE.

IN an entry in his diary, dated 1st February, 1663-4,[1] Pepys informs us that King Charles the Second mightily laughed at Gresham College [the Royal Society], "for spending time only in weighing of ayre, and doing nothing else since they sat." That air is possessed of weight, a fact now familiar to every one, was at this time a novelty even to philosophers. The Torricellian experiment,[2] and the discoveries which resulted from it, had revealed "a new

[1] The former date according to the old, the latter according to the new style. Under the old style the year ended on the 24th of March. The new style came into force in 1752, which year commenced on the 1st of January.

[2] See *post*, p. 3.

world of air," and had opened up to scientific research a field altogether unexplored.

Galileo had found the received opinions regarding phenomena connected with the physical properties of the atmosphere of the earth, as unsatisfactory as the theories touching the mechanism of the heavens. The dogma that *nature abhors a vacuum*, had become superseded by the simpler and more intelligible hypothesis, that the atmosphere is a fluid resting upon the surface of the earth, whose tendency to flow into and fill all vacant spaces is solely the result of its own weight and pressure.

According to Bossut,[1] the discovery of the pressure of the atmosphere was made in the following manner: The engineers of Cosmo de' Medici, Grand Duke of Tuscany, had constructed a common sucking pump, in which it was necessary that the water should rise under the bucket to a greater height than thirty-two feet,[2] and finding they could not draw it above that height, they applied to Galileo for the reason. The philosopher was at a loss how to account for it, but suggested that nature's abhorrence of a vacuum ceased when the water reached a height of thirty-two

[1] *A General History of Mathematics*, translated from the French of John Bossut, London, 1803, pp. 252-253. For accounts of the discovery of the atmospheric pressure see also—Ewbank's *Hydraulics and Mechanics*, 15th ed., p. 187. *La Vie et les Ouvrages de Denis Papin*, par L de la Saussaye et A. Pean, Vol. I., p. 68. Muirhead's *Life of Watt*, 2nd ed., p. 128.

[2] French measure.

feet. His utterance was regarded as oracular by the engineers, but the explanation which he gave did not satisfy Galileo himself. By experiments of another kind, he afterwards began to understand that the atmosphere is possessed of weight.

After the death of Galileo (on the 8th of January, 1641–2), his pupil Torricelli conceived an experiment by means of which the weight of the atmosphere might be tested. He concluded that if it were balanced by a column of water thirty-two feet in height, it ought in like manner to be balanced by a proportionately shorter column of a heavier liquid. In 1643 he tried the celebrated experiment with mercury, and found that a column of this liquid was kept up only twenty-eight inches in a vacuous tube, or one-fourteenth of the height of water under the same circumstances. Mercury being fourteen times heavier than water,[1] the new theory was thus proved in a striking manner to be correct.

The fame of the surprising discoveries of the Italian philosophers, in connection with the nature of the vacuum and the properties of the atmosphere, was soon spread abroad. The subject was taken up with much interest in other countries, and the experiments which were made confirmed the new theory and shed further light upon it.

[1] To speak more exactly, mercury is about 13½ times heavier than water.

The French philosopher Pascal, having satisfied himself of the truth of the conclusions of Torricelli, conceived that the pressure of the atmosphere should be less at the summit of a mountain than upon the surface of the earth.[1] He projected the famous experiment, on the Puy de Dôme, in Auvergne, which was carried out by his brother-in-law Perrier, in 1648. The result proved precisely as Pascal had anticipated. The mercury fell in the tube as Perrier ascended with it up the mountain, and when he reached the summit it was three inches lower than when at the base.[2]

Otto von Guericke, burgomaster of Magdeburg, in Germany, pursuing the same subject, invented (in 1650) an instrument for producing a vacuum, or in other words, an *air-pump* (Fig. 1). In 1654 he exhibited a number of experiments to Ferdinand III. and his court, at the diet of Ratisbon, demonstrating the effects of the atmospheric pressure. The practical character of these experiments will be readily understood from the following account of part of the apparatus employed by him :—[3]

[1] This had also occurred to Descartes.

[2] Pascal published in 1647 his *Nouvelles Expériences touchant le Vuide.* In 1663, a year subsequent to his death, was published his *Traitez de l'Équilibre des Liqueurs et de la Pesanteur de la Masse de l'Air.*

[3] The well-known *Magdeburg Hemispheres* played an important part in Guericke's experiments, but are not immediately connected with our subject.

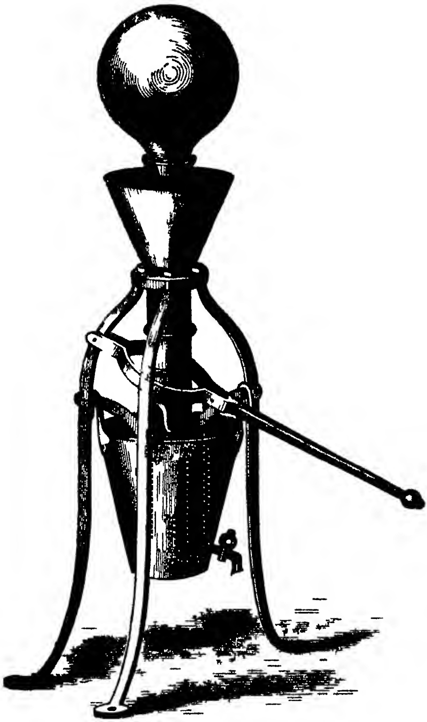

FIG. 1.—GUERICKE'S AIR PUMP.

The copper bowl fastened to the upper end of the barrel, and the pail of tin plate attached to its lower end were filled with water, or oil to prevent leakage of air at the joints The machine had no valves, merely a plug in the top of the barrel and a stop cock on the receiver

An air cylinder *a* (Fig. 2), about twenty inches high and fifteen inches wide, having its sides perfectly even and parallel, was fixed firmly in a vertical position

by the ring S. A piston, P Q R, was made to fit exactly the inside of the cylinder, P being of iron and Q wood, and the rounded head R, formed of hard oak, had a groove on its edge which was filled with flax or hemp. The piston was let into the cylinder, and its iron handle was passed through the ring of the arm O (Fig. 3) in such a manner that it could play freely up and down through the whole height of the cylinder, and at the same time be preserved in a straight line. The piston being near the bottom of the cylinder, and

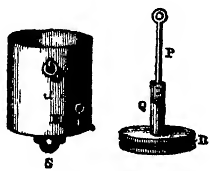

FIG. 2.—GUERICKE'S CYLINDER AND PISTON

the stop-cock X closed, the joint efforts of twenty or more men could not raise it more than half-way up.

The piston being in this position, a large glass receiver, which had been made perfectly vacuous (by an air-pump), was then applied to the stop-cock ; and when the men were exerting their utmost force, on a communication being opened between the receiver and the cylinder, the piston was suddenly forced down to the bottom of the cylinder in spite of the greatest efforts of the men to keep it up.

The raising of a great weight by pumping out the air from under the piston in the above machine, afforded an equally forcible illustration of the effects of the

FIG 3.—GUERICKE'S CYLINDER AND PISTON MACHINE, 1654.

atmospheric pressure. The piston being at the top of the cylinder, and attached to a scale loaded with 2,686 lbs. (Fig 4), a little boy, by means of a small syringe applied at the stop-cock x to pump out the

air, was able to bring down the piston and raise the weight.[1]

The Honourable Robert Boyle was one of the earliest

FIG 4 —GUERICKE'S MACHINE APPLIED TO RAISE WEIGHTS 1654

and most assiduous cultivators of the new philosophy in England He was the seventh son of Richard, Earl

[1] *A Treatise on the Steam Engine*, by John Scott Russell, M A., F R.S., Edinburgh, 1851, p. 43. The first account of the Magdeburg experiments was published in 1657, by Gaspar Schottus in his treatise

of Cork, and was born at Lismore, in Munster, in January, 1626-7. He was educated at Eton school, and after spending three or four years there he passed several years on the Continent (1639-44). He spent the winter of 1641-2 at Florence, employing much of his time in learning Italian, "and his spare time in reading modern history in Italian, and the new paradoxes of the great star-gazer Galileo." During his stay there, Galileo died at a village within a league of the city.[1] After returning to England, Boyle became one of the first members of the Philosophical Society, which, in 1662, largely owing to his exertions, was incorporated as the Royal Society.

Having heard of the success of Otto von Guericke, Boyle determined to provide himself with an air-pump. With this object he applied to Greatrex, a well-known London instrument-maker of the time, but between them they could not succeed in constructing a serviceable machine. Boyle next had recourse to Robert

De arte Mechanicâ, Hydraulico-Pneumaticâ, &c., pp. 444-484. Guericke himself published in 1672 his work entitled *Ottonis de Guericke Experimenta nova (ut vocantur) Magdeburgica de vacuo spatio.* In this work he successfully refuted the assertion of Augustus Hauptmannus, doctor of medicine, in his *Berg-be-deneken*, anno 1658, Lipsiæ, "that it would not be possible to either angel or devil to bring about a vacuum." [See *Catalogue of the Special Loan Collection of Scientific Apparatus at the South Kensington Museum*, 1876, 3rd ed., London, 1877, p. 158.]

[1] *The Works of the Honourable Robert Boyle*, by Thomas Birch, D.D., F.R.S. London, 1744. Vol. I., p. 13.

Hook,[1] then a youth of three and twenty, of great mechanical genius, and with his assistance contrived the first English air-pump. It appears to have been commenced in 1658, and finished early in 1659. Like Guericke's machine, it consisted of a single inverted barrel[2] (Fig. 5). With this engine Boyle conducted a series of experiments, "touching the weight and spring of the air and its effects," of which he published an account in 1660. In May, 1661, he presented the air-pump to the Philosophical Society, to whom it was an object of much interest.[3]

The study of science by means of observation and experiment, had already obtained many zealous adherents in nearly all the countries of Europe. Scientific societies rose into prominence, almost simul taneously, in Italy, Germany, France, and England. Of these, the "Accademia del Cimento" was established at Florence in 1657, but after a short career of ten years was suppressed, at the instance, it is stated, of

[1] Hook was born at Freshwater, Isle of Wight, in 1635. About 1653 he went to Oxford, and while there became a member of the Philosophical Society, whose meetings were then held at Oxford. He afterwards became assistant to Mr. Boyle. He was appointed Curator of Experiments to the Royal Society in 1662, and in 1664 Professor of Mechanics, and also Professor of Geometry in Gresham College. In 1677 he became secretary to the Royal Society.

[2] The object of inverting the barrel was to enable the pear-shaped receivers, then made use of, to be attached to the pump with facility.

[3] *On the Early History of the Air Pump in England*, by George Wilson, M.D., F.R.S.E., in *The Edinburgh New Philosophical Journal*, Vol. XLVI., p. 330, *et seq.*

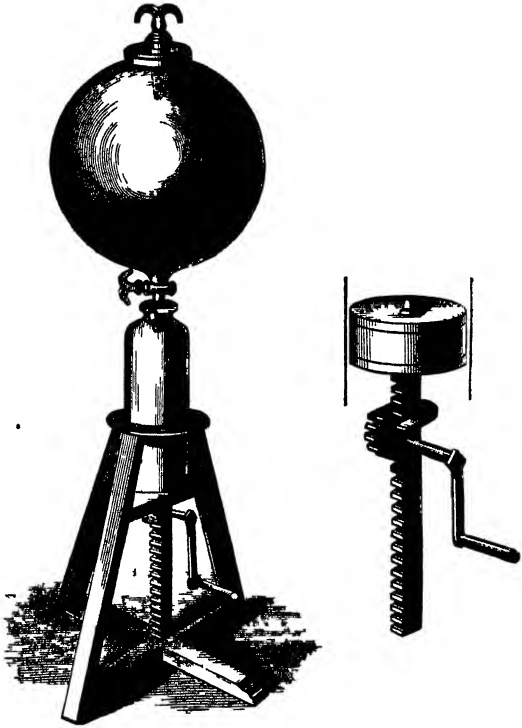

FIG 5.—BOYLE AND HOOKE'S FIRST AIR PUMP, 1658-9

the papal government,[1] which had from the first offered a determined opposition to philosophical inquiry More fortunate were the "Royal Society of London

[1] *History of the Conflict between Religion and Science,* by John William Draper, M.D , LL.D., 11th ed , London, 1878, p. 300. The

for improving natural knowledge," incorporated by royal charter, as above stated, in 1662, and the "Académie Royale des Sciences," established at Paris by Louis XIV., at the suggestion of his minister Colbert, in 1666,[1]—both of which continue to flourish with unabated vigour at the present day.

After the lapse of a few years, Boyle became desirous to resume his researches into the properties of air. About 1667, again with the assistance of Robert Hook, he constructed a new and improved air-pump. Like the former one, it had a single brass barrel. The barrel, however, was no longer inverted, but stood upright (Fig. 6). In order to ensure greater tightness, it was placed in a tank filled with water which covered the mouth of the barrel, and thus wholly prevented any leakage of air at the sides of the piston, and kept the leather of the piston always wet, and consequently "turgid and plump." An account of the experiments made with the second engine was published by Boyle in 1669, and again for some years his attention was directed to other matters.[2]

experiments of the *Academia del Cimento* were published at Florence in 1666. Pneumatic phenomena constituted one of the principal subjects of research. In Germany the *Imperial Academy of the Curious in Nature* was founded in 1662.

[1] A Philosophical Society had existed in France for a considerable number of years previous to this date.

[2] Dr. G. Wilson, *On the Early History of the Air Pump in England*, ut supra.

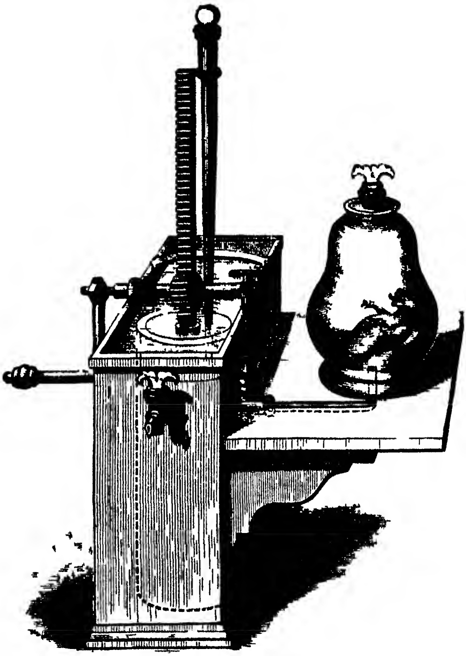

FIG. 6.—BOYLE AND HOOKE'S SECOND AIR PUMP, 1667.

The receiver stood upon a separate plate, and was exhausted of air by means of a pipe communicating with the barrel, and fitted with a stop-cock. The piston was provided with a small vertical aperture, which was left open during the down stroke, but closed by means of a long plug during the up stroke. On the piston arriving above the mouth of the pipe leading to the receiver, the stop-cock was opened and the air in the receiver expanded into the vacuous cylinder, the operation being repeated until the whole was exhausted.

At the date of the establishment of the Royal Academy of Sciences at Paris, the celebrated Dutch philosopher, Christian Huyghens, of Zuylichem, was already in the zenith of his fame. Born at the Hague,

of a noble family, in 1629, Huyghens at an early age exhibited a remarkable aptitude for scientific pursuits. While still under twenty, his achievements in geometry had attracted the attention of Descartes. A little later, his improvements in horology, and his discovery of the ring of Saturn, by means of the great perfection which he had given to telescopes, caused him to stand foremost among the philosophers of the age. The desirability of securing the services of this distinguished foreigner for the French Academy, led Colbert, in 1665, to offer him, in the name of Louis XIV., a large salary, together with lodgings in the library of the king. The proposal was accepted by Huyghens, and in the following year he became one of the sixteen members of the new Academy and took up his abode in Paris.[1]

A few years afterwards (1671), a young French doctor. Denis Papin, was, through the instrumentality of Huyghens, appointed Curator of Experiments in the laboratory of the Academy attached to the royal library. Papin was born at Blois, in 1647. His family professed the reformed religion. In 1661, or 1662, he repaired to the protestant University of Angers to devote himself to the study of medicine, and there graduated as doctor in 1669. His natural bent, however, appears

[1] *The Philosophical Transactions*, abridged by Drs. Hutton, Shaw, and Pearson. Vol. I., p. 326, note. *Denis Papin, sa Vie et son Œuvre*, par le Baron Ernouf. Paris, 1874, pp. 29-31.

to have been towards mechanics and natural philosophy rather than to medicine. Huyghens also had studied at the University of Angers, and to this circumstance, and perhaps in some measure owing to the fact of Madame Colbert being, like Papin, a native of Blois, may be attributed his being brought to Paris by Huyghens.[1]

Installed in the laboratory of the Academy, Papin commenced a course of scientific investigation after a programme drawn up by Huyghens. This included, among other things,—the making of experiments on the vacuum by the pneumatic engine[2] or otherwise, and the determination of the weight of air,—the examination of the force of gunpowder, by inclosing a small quantity in a very strong case of iron or copper,—the examination in like manner of the force of water rarefied by fire.[3]

An account of the experiments made was published by Papin in 1674, in a memoir entitled "New experiments on the vacuum, with a description of the machines used for making them." [4]

[1] *La Vie et les Ouvrages de Denis Papin*, par L. de la Saussaye et A. Pean, Paris and Blois, 1869. Vol. I., P. 1, pp. 85, 89, 90.

[2] The air-pump first used by Huyghens and Papin was constructed after the model of Boyle and Hook's. [*Vie de Papin*, par L. de la Saussaye et A. Pean. Vol. I., p. 103.]

[3] *Denis Papin, sa Vie et son Œuvre*, par le Baron Ernouf, pp. 36, 37.

[4] *Nouvelles Expériences du Vuide, avec la Description des Machines qui servent à les faire.* Paris, 1674. *Denis Papin*, par le Baron Ernouf, pp. 40-41.

In the following year (1675), Papin left Paris and proceeded to London, in hopes of obtaining a better position there [1]

[1] *Denis Papin*, par le Baron Ernouf, p. 43; Birch's *Boyle*, Vol. IV., p. 96. It has been frequently stated (notably in the *Life of Watt* by M. Arago, Edinburgh, 1839, p. 37) that Papin was driven out of France by the revocation of the Edict of Nantes, but this appears to be erroneous, as the revocation of the Edict did not take place until ten years later (1685).

CHAPTER II.

ATTEMPTS TO DERIVE A NEW MOTIVE POWER FROM THE FORCE EXERTED BY THE ATMOSPHERE IN RUSHING INTO A VACUUM.

DURING the period which had elapsed since the discovery of the pressure of the atmosphere, little progress appears to have been made towards applying the new force to any useful purpose. The discovery, as has been already seen, was first suggested by phenomena connected with the raising of water, and the earliest attempts to utilize this power were directed towards the raising of this liquid. Only one notice of an attempt of this kind, previous to the date at which we have arrived, is known to the writer, and we have no information regarding the form of apparatus employed. It occurs in the warrant for a grant from King Charles the Second to Sir Samuel Morland,[1] "for the space of fourteen years,

[1] Sir Samuel Morland was a skilful engineer of the reign of Charles II. He was the inventor of the modern forcing-pump, besides

to have the sole making and use of a new invention of a certain Engin lately found out and devised by him, for the raising of water out of any mines, pits, or other places, to any reasonable height, and *by the force of Aire and Powder conjointly.*" It is dated Whitehall, December 11th, 1661.[1] There is no further mention of the above invention of Morland, nor of any other attempt of the kind, for a considerable number of years.

Regarding the next proposal, however, we have a sufficiently detailed account. It was made in France by Jean de Hautefeuille in 1678, his attention, he informs us, having been directed to the subject in connection with the numerous schemes suggested for supplying the new palace at Versailles[2] with water. He proposed two methods for raising water, in both of which gunpowder was to be employed, but in the first only the pressure of the atmosphere was brought into play. His plan for utilizing the atmospheric pressure was as follows:—A B (Fig. 7—No. 1), an air-tight box or cistern, was to be fixed at a height of about thirty feet above the level of the water to be raised. C D E F, is a pipe leading from the cistern to the reservoir.

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many ingenious instruments. In 1681 he was sworn "Master of Mechanics" to the King [*Annals of Windsor*, by Tighe and Davis. London, 1858, p. 388]. He also invented some kind of high-pressure steam-engine. See *post*, p. 108, note.

[1] *Warrant Book*, V., p. 85; Public Record Office, London.

[2] Louis XIII. built a hunting-seat at Versailles about 1632. Between 1661 and 1687 Louis XIV. enlarged it into a magnificent palace, which became the usual residence of the kings of France.

G, G, are valves; H, a slide for introducing the gunpowder; I, a cock for emptying the cistern.

The charge of gunpowder having been exploded inside the cistern, the air contained in it is expelled by the valves G G, and a vacuum being formed, the water is driven up from the reservoir below by the atmospheric pressure.

K L is a similar cistern, arranged so that by means of the cocks at M and D, it might be filled alternately with A B.

The second apparatus described by Hautefeuille was designed for raising

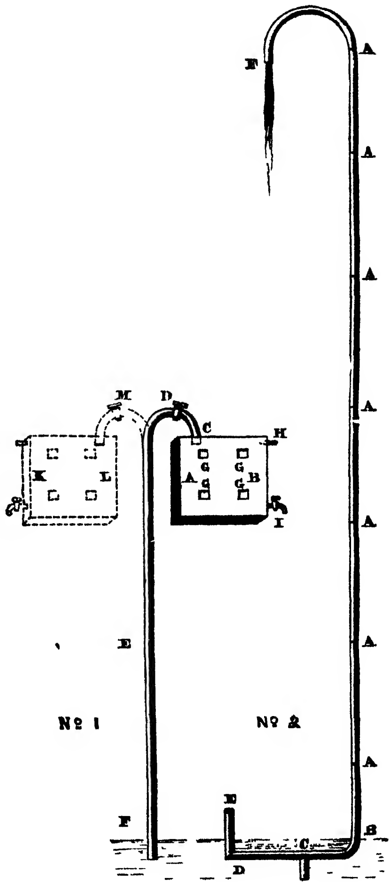

FIG. 7.—HAUTEFEUILLE'S TWO METHODS OF RAISING WATER BY GUNPOWDER, 1678.

water by the expansive force of gunpowder alone. E D C B A F (Fig. 7—No. 2), is a continuous pipe. The portion B C D, which is under the surface of the water, fills of itself, a valve at C allowing the liquid to enter but preventing it from getting back into the reservoir. In B A F are valves A A A, little distances apart. A charge of gunpowder being exploded within the pipe at E, the inclosed water is driven upwards through B A F.[1]

We cannot say whether Sir Samuel Morland employed a cylinder and piston in his apparatus above mentioned; we know that Hautefeuille did not. So far as our information goes, it is to Huyghens that the merit belongs of having constructed the first *motive engine* consisting of a cylinder and piston.[2] He employed gunpowder *to produce a vacuum under the piston*, and the atmospheric pressure performed the work. In the hands of subsequent inventors this simple machine of Huyghens was developed into the modern steam-

[1] *Pendule Perpetuelle, avec un nouveau Balancier, et la manière à élever l'Eau par le moyen de la poudre à canon*, &c. Paris, 1678, pp. 14-16. *La Vie et les Ouvrages de Denis Papin*, par L. de la Saussaye et A. Pean, pp. 139-143.

[2] It may be mentioned however that Hook is stated to have *proposed* "a steam-engine on Newcomen's principle" in 1678.—See the Life of Hook in *Brewster's Edinburgh Encyclopædia.* What kind of engine is meant or what foundation there is for the statement, the writer is unable to say. Hook was dead several years before Newcomen's engine was invented.

engine, the various steps in its improvement from its first appearance being easy to be traced.

Huyghens' apparatus was first constructed in 1678, or 1679.[1] Following close upon the publication of the above proposals of Hautefeuille, in reference to new applications of gunpowder, it seems not improbable that they gave occasion to his attention being directed to the subject.[2] An account of his invention was given in a memoir which he communicated to the Royal Academy of Sciences in 1680, entitled "A new Motive Power by means of Gunpowder and Air."[3] In this he states that a want had long existed of a contrivance by means of which the force of gunpowder might be brought to perform useful work, instead of only being used as hitherto for the firing of cannons and carbines, and the blasting of mines. He describes an engine he had contrived for this purpose, consisting of a hollow cylinder A (Fig. 8), well polished within and of uniform size throughout. B, a movable piston inserted into the top of the cylinder, the upper porton of which is surrounded by a small quantity of water. C, C, two apertures, each one-half the diameter of the cylinder. D, D, tubes of moist and soft leather secured to little cylinders which are fastened to the main cylinder at the apertures,

[1] See *post*, p. 24.

[2] The problem of raising water from the Seine to supply the palace at Versailles caused great attention to be directed at this time to all forms of motive power available.

[3] *Nova vis movens mediante pulvere nitrato et aëre.*

(one of the tubes being shown extended, the other hanging). E, E, holdfasts, by which the cylinder is joined to the case in which it sits, which is not shown in the figure. F, F, a cord attached to the piston and passing over a pulley G, for the purpose of raising

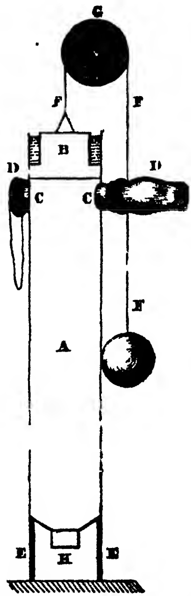

FIG 8.—HUYGHENS' GUNPOWDER AND AIR ENGINE, 1678–9

whatever is attached to it. H, a small box for receiving the charge of gunpowder, attached to the bottom of the cylinder by means of a screw, a leather ring being employed to aid in making the joint air-tight.

On the explosion of the charge, the air contained in the cylinder was driven out through the leather tubes C D, C D, which were momentarily extended, but immediately closed again by the external air; and the cylinder being vacuous, the piston B was driven down by the atmospheric pressure, drawing with it the cord F, and raising whatever was suspended by it.[1]

In a tract which he published in 1682,[2] Hautefeuille refers to the experiments which had been made at the Royal Academy for raising *solid bodies* by means of gunpowder. He gives a description of the above apparatus, and states that he was assured that a dram of gunpowder, in a cylinder seven or eight feet high and fifteen or eighteen inches in diameter, had raised into the air seven or eight boys who held the end of the rope (see Fig. 9); and that it had in like manner raised from 1,000 to 1,200 pounds' weight.

Another account of Huyghens' invention appeared in the *Nouvelles de la République des Lettres* for the month of May, 1687. From this account it seems that two and a half years previous to this date, a problem had been propounded to certain *virtuosi*

[1] *Christiani Hugenii Opera*, G. J. Gravesande, Lugduni Batavorum, 1751, Vol. I., p. 280.

[2] *Réflexions sur quelques Machines à élever les Eaux*, &c. Paris, 1682, p. 9. It has been said that Hautefeuille claims the invention as his own, but this is clearly incorrect. What he says is that he had suggested the use of gunpowder three or four years previously for raising *water*.

touching new uses to which gunpowder might be applied. Only one favourable answer was evoked, which evidently came from the pen of Huyghens It is presented in the form of an extract from a letter to a friend, under date 24th May, 1686. The writer of the letter states that he had received the problem

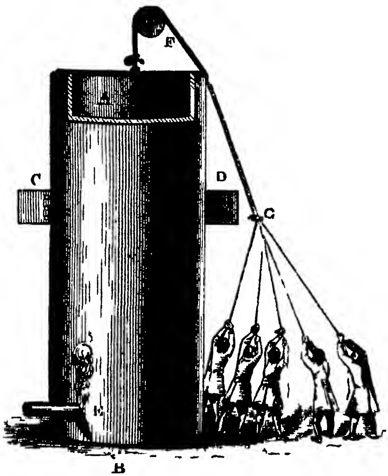

FIG 9—HUYGHENS' ENGINE, 1682 (Hautefeuille)

communicated regarding the new use of gunpowder, and that in his opinion the project was not hopeless Seven or eight years previously he had shown to M. Colbert a machine which he had made to be constructed for this very purpose, and which was registered at the time in the Academy. Its effect was such that a small

quantity of gunpowder, enough to fill a thimble, lifted some 1,600 pounds to the height of five or six feet, not violently, but with a moderate and equal force, and four or five boys whom M. Colbert caused to take hold of the rope attached to the machine were lifted with great ease into the air. Some difficulty, however, was experienced in obtaining a continual repetition of the force.

From this point the invention leaves the hands of Huyghens, but was taken up and further perfected by his former subordinate and friend Papin We shall therefore now follow the various steps in Papin's career from the time when he proceeded to London in 1675.

CHAPTER III.

PAPIN IN LONDON.—HIS FIRST PNEUMATIC ENGINES.

SHORTLY after arriving in the metropolis of England, Papin addressed himself to the Honourable Mr. Boyle, and in August, 1675, we find him already employed by Mr. Boyle in making a translation of a theological treatise.[1] Ere long he was put to a class of work more congenial to his disposition, viz. the prosecution of another series of pneumatical experiments.

Papin had brought to Mr. Boyle a copy of his treatise, on the experiments made by Huyghens and himself at Paris, which greatly interested Mr. Boyle. The opportunity afforded by the presence of Papin, who had moreover a double-barrelled air-pump of his own invention[2] (Fig. 10), decided Mr. Boyle to commence a

[1] *Vie de Papin*, par L. de la Saussaye et A. Pean. Vol. I., p. 95.

[2] It is sometimes stated that Papin invented the double air-pump while in the employment of Boyle, but the reason given by Boyle for allowing him to use his own pump, viz., because he was more accustomed to it, seems to point to his having used it a good deal before

third series of experiments with the assistance of Papin. These experiments were begun in July, 1676, and continued till February, 1679. Some of the later experiments, Mr. Boyle informs us, about flesh, about fruit, and about boiling of meat, were propounded

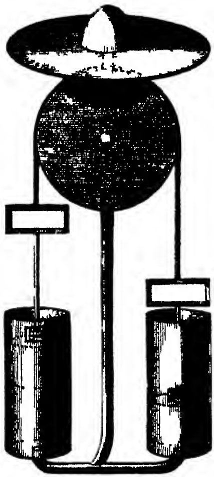

FIG 10.—PAPIN'S DOUBLE AIR-PUMP, ABOUT 1675–6

This was the first air-pump provided with valves, which were opened and closed by the action of the machine The operator worked the pump with his feet, placing one in each of the rectangular "stirrups" The barrels, or cylinders, were partially filled with water to render the pistons air-tight

by Papin for a particular end of his own, somewhat different from the design of the rest of the experiments.[1]

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he came to Boyle. See Birch's *Boyle*, Vol. IV., pp. 96-97. There is, however, no allusion to a double-pump in the tract published by Papin in 1674.

[1] Birch's *Boyle*, Vol. IV., p. 97.

Soon after the conclusion of his engagement with Mr. Boyle, the first connection of Papin with the Royal Society commenced At the meeting of the Society held May 22nd, 1679, Mr. Hook, the secretary, "had leave to introduce Mons Papin, a gentleman who staid in the outer room, with an intention to shew an experiment to the Society which was singular and new."[1] This had reference to his method of cooking in a close vessel at a high temperature by means of an apparatus invented by him and known as "Papin's Digester"

On June 19th, we find Papin exhibiting to the Royal Society "a new kind of wind-fountain of his own contrivance;"[2] and at the meeting of the Society on July 3rd, Mr Hook was empowered to employ Papin for the writing of all such letters as should be ordered to the correspondents of the Society, at so much per letter; an arrangement soon afterwards altered for a certain payment of 20*l.* per annum, with lodgings in Gresham College if they could be found.[3]

This engagement was of very short duration. At the meeting of the Society on December 10th, 1679, "it was ordered that Mons. Papin should be discharged, but that he be allowed for the time till he be discharged and paid accordingly."[4]

[1] Birch's *History of the Royal Society*, Vol. III., p. 486.
[2] *Ibid.* Vol. III., p. 490 [3] *Ibid.* Vol. III., p. 491.
[4] *Ibid.* Vol. III., p. 514.

From this time till near the close of the following year nothing is heard of Papin, but it would appear from statements of his own, to be hereafter referred to, that he spent part of the time at least in Paris, living with Huyghens, and assisted in the invention of the gunpowder engine.[1] At the meeting of the Royal Society on December 2nd, 1680, we find him again present and exhibiting his "boiling engine" to the Society. At the following meeting (December 8th) his book, entitled *A new Digester or Engine for softening bones, &c.*, was ordered to be printed.[2] He is sometimes stated to have been elected a Fellow of the Royal Society on December 16th, through the influence of Mr. Boyle; but this appears to be incorrect, as in the order of the

[1] See *post*, p. 47.

[2] Birch's *History of the Royal Society*, Vol. IV., p. 60. Papin used a safety-valve on his Digester, and is usually credited with being its inventor; but it appears to have been known at a much earlier date. (See Ewbank's *Hydraulics*, 15th ed. p. 451.)

The Digester continued to receive Papin's attention from time to time for many years. The early history of this curious machine is not without some amusing incidents. At the time of its invention Papin suggested its use in hospitals to the Government of Charles II., but the court laughed at the Digester and its products. (*Denis Papin*, par le Baron Ernouf, p. 55.)

Evelyn tells us in his Diary [12th April, 1682] of a supper cooked by the Digester, to which he accompanied some of the Fellows of the Royal Society, who wished, by practical experiment, to make trial for themselves of its culinary value. In concluding his account of the repast he observes—"This philosophical supper caus'd much mirth amongst us, and exceedingly pleas'd all ye company. I sent a glass of ye jelly to my wife, to the reproach of all that the ladies ever made of their best hartshorn."

Council dated December 8th he is described as "Doctor of Physick, and Fellow of this Society."

In the beginning of the year 1681 Papin again left England. At the house of Boyle he had made the acquaintance of Sarotti, the representative of the Venetian senate at the English court. Sarotti was about to establish a philosophical society at Venice, and proposed that Papin should accompany him there to take the post of Curator of Experiments to the society. Papin accepted the offer, and took his departure for Italy accordingly.[1] Here, however, he remained only about three years, after which he returned once more to London.

He now renewed his connection with the Royal Society, and on April 2nd, 1684, was appointed temporary Curator at a salary of 30*l.* per annum.[2] His principal duty was to bring experiments before every meeting of the Society, a necessity which could not fail to serve as a powerful stimulus to his inventive faculties. Among the numerous notices of the contrivances which he exhibited at the Royal Society's meetings, we shall confine our attention to such only as bear immediately on our subject, which do not begin until rather more than a year after he had obtained the above appointment.

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1 *Vie de Papin*, par L. de la Saussaye et A. Peun, Vol. I, p. 111.

2 Weld's *History of the Royal Society*, London, 1848, Vol. I., p. 286. Birch's ditto, Vol. IV., p. 277.

At the meeting held on June 3rd, 1685, Dr. Papin, we are informed, produced a draught of a fountain of his own contrivance, which being liable to be spoiled by being removed, he desired the Society to appoint some persons to see the working of it for a whole day together, whether it would not run constantly without losing anything of its strength. The machine was proposed as a puzzle to the ingenious, its principle being kept secret.[1]

According to the inventor's desire the Royal Society ordered that the thing should be observed. Mr. Hook saw it for nearly half an hour, there being other persons to observe it longer, who watched it about four hours together. They went away not doubting but the water did circulate in the engine, and might continue a great deal longer, since it ran still as constantly and as high as at their first coming: and Mr. Boyle, knowing the whole contrivance, stated that it might continue for a whole day and more, and thought it worthy to be left for some time to the inquiry of ingenious men.[2]

The principle of the fountain was not divulged by Papin till the beginning of the following year (January 1685-6), when he explained that the water was made to circulate by the air being alternately sucked out of and pushed back into certain vessels, by means of a pipe

[1] Birch's *History of the Royal Society*, Vol. IV., p. 405.

[2] *Phil. Trans.* No. 173, p. 1093.

led from a syringe, or piston-pump, opened and closed by a person in concealment (Fig. 11).

The contrivance itself was a mere toy, but it gave occasion to Papin to propose a plan, by which he thought the stream of a river might be applied to raise water out of a mine far distant from it; or the stream of the Thames might keep constant waterworks in Windsor

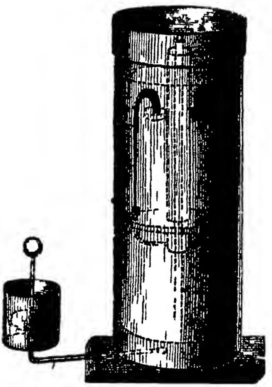

FIG 11—PAPIN'S WIND-FOUNTAIN, 1685.

Castle almost as easily as in the lowest fields; or the river Seine might do the same at St. Germain, and perhaps at Versailles too, notwithstanding the great distance;—the water being raised from stage to stage by means of receptacles placed one above the other at distances of twelve or fifteen feet. His scheme was as follows:—

"A B, A B (Fig. 12), are several receptacles set above one another, which must be well shut and soldered everywhere. C D D, C D D, are two slender pipes, by which the first and third receptacles communicate with

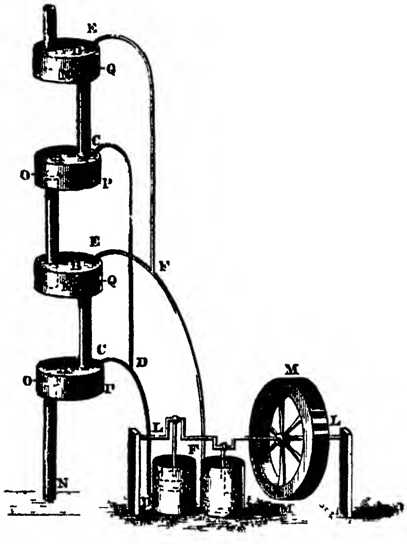

FIG 12.—PAPIN'S PNEUMATIC ENGINE FOR RAISING WATER, 1695–6.

the pump H H. E F F, E F F, two other slender pipes, by which the second and fourth receptacles have a communication with the pump I I. H H, I I, two pumps whose plugs are so moved by the axis L L, that when one descends the other ascends. M M, a wheel fastened to the axis L L, that it may be moved by the stream of

a river. N O, P Q, N O, P Q, are large pipes for the water to ascend, from a lower to a higher receptacle. O Q, O Q, are valves fitted to the top of the said pipes to prevent the water from descending.

"Now it is plain that when the plug in the pump H H ascends, the air comes in through the pipes C D D, by which it is rarefied in the first and third receptacles, marked A A: by which means the water may be driven up into the receptacles through the pipes N O; because at the same time the plug in the pump I I descends, it causes the air to return to its ordinary pressure in the second and fourth receptacles, that it may be capable to force up the water through the said pipes N O, and the lowest pipe draws the water that lies open to the air. For the same reason, when the plug in the pump I I ascends, the air must come in through the pipes E F F; and so be rarefied in the second and fourth receptacles, marked B B; by which means the water is forced up into the said receptacles through the pipes P Q, P Q; because at the same time the plug in the pump H H descends, it causes the air to return to its ordinary pressure in the first and third receptacles, so that it is enabled to force up the water through the said pipes P Q."[1]

An account of the above proposal was published in the *Nouvelles de la République des Lettres* for May and

[1] *Phil. Trans.* No. 178, p. 1274. Abridged by Drs. Hutton, Shaw, and Pearson.

June following (1686), and in the same periodical for the month of December appeared certain objections urged by one Mr. Nuis against the apparatus. These objections were read from the *Nouvelles* at the meeting of the Royal Society on March 23rd, 1686-7, and at the same time were met by Papin.[1] From his explanation it appears, that at a distance of 12,000 feet he considered that the air would be driven from the receptacles into the pumps by a force equal to ten feet of water; that for great distances there should be as many pumps as receptacles; and that to raise water sixty feet, thirteen or fourteen receptacles would be required and as many pumps.[2]

This application of the machine ceased to receive further attention, but led to another proposal being made soon afterwards. At the meeting of the Society on June 29th, 1687, "a paper of Dr. Papin was read about applying his engine for raising water by the rarefaction of air to the raising of any sort of weight out of deep mines."[3] To make his machine suitable for this new application, Papin had introduced important modifications into it. As thus altered, it is described by him as follows:—

"Let a wheel such as A A (Fig. 13) be constructed and placed at the mouth of the mine, so that the rope, B B B B,

[1] Birch's *History of the Royal Society*, Vol. IV., p. 529.
[2] *Phil. Trans.* No. 186, p. 263.
[3] Birch's *History of the Royal Society*, Vol. IV., p. 544.

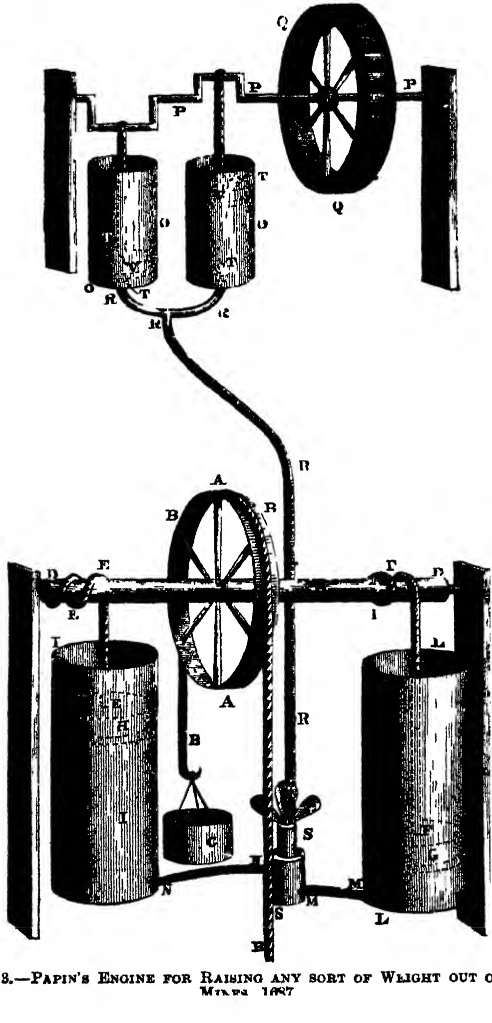

Fig. 13.—Papin's Engine for Raising any sort of Weight out of Deep Mines, 1687

carried over the said wheel, may send two buckets alternately into the mine, one of which is marked C in the figure, which [buckets] fastened to the opposite ends of the said rope always move in opposite directions: the one going down, the other as surely moves upwards, bringing with it water, or ore, or other stuff, out of the bowels of the earth. Let an axle, D D D, pass through the centre of the said wheel and there be secured; and let two ropes, E E E, F F F, be wound around the said axle in order that the two pistons H and G, fastened to the lower ends of the said ropes, cannot but alternately ascend or descend, and the one descending the other must necessarily be borne upwards. We must suppose these pistons to be exactly fitted to two tubes, I I, L L, and thus it is clear that if the air be removed through the pipe M M from the tube L L, for example, the piston G will be pressed downwards with great force by the pressure of the external air, and the axle D D D, together with the wheel A A, will be made to revolve by the rope F F; whence it follows that the piston H, together with the bucket C, is borne upwards: then the bucket C might be emptied of the stuff brought up from the mine, and as at the same time the piston H must arrive at the top of the tube I I, the air may then be drawn out of the tube I I through the pipe N N, and so the piston H be pressed down in turn and the piston G be brought up with the bucket fastened to the other end of the rope B B and the stuff contained in it. But it

must be arranged that the external air be admitted below the ascending piston, otherwise it could not possibly be removed from the opposite piston. Let that, however, only be done, and this alternate exhaustion of the air be continued, it is clear that the work aimed at can also be continuously accomplished. It therefore only remains for me to show a method by which the said extraction of the air may be satisfactorily performed by a river even a long way off.

"Let O O, O O, be two pumps of which the pistons V V are moved alternately upwards and downwards by the revolution of the axle P P P P, to which axle the wheel Q Q to be driven by some river is firmly fastened; it is clear that if the said pumps O O, O O, and the pistons of the same with the valves T T, T T, be properly constructed, in the manner of a common sucking-pump, they must necessarily continuously draw air through the pipe R R R R and the orifice S S. The orifice S S, moreover, can be easily arranged so that by the due turning of the spindle a double effect may be produced: 1. That an entrance is certainly opened to the external air below the piston about to ascend, but closed below the piston about to descend: 2. That a communication is permitted with the pipe R R R R below the piston about to descend, but closed below the piston about to ascend: we shall thus easily bring it about that while the piston G, for example, should descend from the upper end of the tube L L, below the

said piston the entrance to the external air is closed, but a communication with the pipe R R through the pipe M M and the orifice S S is open; but below the piston H an entrance to the external air is open and a communication with the pipe R R is closed. And, *vice versâ*, when the piston H is about to descend, the orifices which formerly were opened are immediately closed by the turning of the spindle, and those which were shut are opened, and thus we may obtain the effect aimed at.

"Some contrivance might be devised by means of which the machine itself might turn the spindle at the proper time; but I think it would be better for a man always to watch the work and the emptying of the buckets when they land at the mouth of the mine."[1]

Such was the first *vacuum engine* proposed by Papin. It was the earliest suggestion of a feasible method by which a continuous and uninterrupted useful effect might be derived from the atmospheric pressure. It was an altogether new plan for conveying the power of a water-wheel to a distant point. We are not aware that any machine on this principle was ever

[1] No account of this machine was published during Papin's stay in England. The above description is translated from the *Acta Eruditorum*, anno 1688, p. 644. In his paper he refers to the objections which had been brought against this machine when he had proposed it to the Royal Society of London during the preceding year.

constructed by Papin; the novelty of the suggestion, however, was very creditable to his ingenuity.

Time has proved that the above scheme was perfectly practicable, but at the date of its proposal it met with great opposition. Dr. Hook entered the arena against Papin, and maintained that a rope strained very tight would serve to convey force or motion much better than any such contrivance.[1] This was succeeded by a controversy on the subject between Papin and Hook of some duration, as appears from the following notices:—

"July 6. Mr. Hook read a discourse concerning a way of conveying force to a great distance, which he conceived would best be done by some stiff and inflexible rod, as a wire, or long pole, or the like; and showed the experiment by communicating a force given in the inner hall of Gresham College across the quadrangle by means of a pack-thread, which was found to perform to satisfaction."[2]

"July 13. Dr. Papin gave in a paper in answer to Dr. Hook's objections against the way of conveying force by the rarefaction of air. It was, that his pipes being laid in a trough, and then covered with coarse turpentine, would thereby be kept tight and secure against the passage of the air through any lesser chinks or holes that might be left in them."[3]

"July 20. Mr. Hook read an answer to Dr. Papin's objection to the communication of motion at a distance by rods, with a further explication of the vibration of the rods or poles; as also another discourse, wherein he further explained the great inconvenience of Dr. Papin's way and the impracticability thereof by showing:—1. That it would be next to impossible to make

[1] Birch's *History of the Royal Society*, Vol. IV., p. 544.
[2] *Ibid.* p. 545. [3] *Ibid.* p. 547.

pipes to hold so perfectly as not to leak air in some part. 2. That it would be as difficult to discover one or more such leaks, or when found to stop them. 3. That neither his gutters, nor turpentine, nor molasses, would prevent these difficulties; for that all such a gutter must be uncovered two leagues when such leaks happen; next, the gutters would not do up-hill and down-hill, nor cross roads; and they would be as difficult to keep tight from leaking out those substances; nor would they hinder evaporation. And though it were possible; yet, 4, That the air is the worst of all *media* for conveying such power, there being more strength lost thereby than by any solid *medium* or fluid, as water, &c., because of the great springiness thereof."[1]

At this point the controversy appears to have terminated. Some months later we find Papin directing his attention to the method which Huyghens had proposed for creating a vacuum in a cylinder directly by the explosion of gunpowder, an account of which, as we have already seen, appeared in the Dutch *Nouvelles* for the month of May in this year.

At the meeting of the Royal Society on October 26th, "A paper of Dr. Papin was read concerning a way of applying the force of gunpowder to raise weights, and to other mechanical uses, of which he showed the experiment. It was by rarefying the air included in a cylinder by the flash of the powder, and then applying the weight of the atmosphere to drive down a plug into the evacuated cylinder, being the way mentioned in the *Nouvelles de la République des Lettres*."[2]

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[1] Birch's *History of the Royal Society*, Vol. IV., p. 548. [2] *Ib.* p. 550.

On November 9th, "Dr. Papin gave in a paper about the quantity of air evacuated by the flash of gunpowder in his experiment tried on the 26th of October; which paper was read, and it appeared that forty-six parts of fifty-nine of the whole cavity of the vessel had been emptied of air.

"Dr. Papin repeated the experiment made at the meeting of the 26th of October with a third part of the gunpowder used then, but supposed three times as strong; and the effect was that the air expelled was equal in bulk to 2 lbs. 5 ozs. of water, the powder being about half a scruple." [1]

Soon after this date (viz. on November 23rd) we find Papin requesting payment of arrears of salary, being about to leave England in order to be Professor of Mathematics in the University of Marburg.[2] The last notice of him in connection with the Royal Society at this period is dated December 14th, 1687, on which day he presented to the Society his engine for the circulation of water by the rarefaction of air.[3]

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[1] Birch's *History of the Royal Society*, Vol. IV., p. 551.

[2] *Ibid.* p. 553. Some of Papin's relatives, driven into exile by the revocation of the Edict of Nantes in 1685, were already settled at Marburg. [*Vie de Papin*, par L. de la Saussaye et A. Pean, Vol. I., p. 128.] The revocation of the Edict of Nantes took place shortly after the death of the enlightened and liberal-minded Colbert, who was one of the best friends of the early Protestants in France.

[3] *Ibid.* p. 558.

CHAPTER IV.

PAPIN AT MARBURG.—HIS PROPOSAL TO EMPLOY STEAM, IN LIEU OF GUNPOWDER, TO PRODUCE A PERFECT VACUUM UNDER A PISTON AT SMALL COST.

THE removal of Papin to Marburg caused no interruption to the interest he took in the subjects which had occupied his attention before leaving London. He contributed a paper "On the New Use of Gunpowder,"[1] to the *Acta Eruditorum* of Leipsic for the month of September, 1688.[2] As he claims in this paper to have effected some improvements on the machine of Huyghens, and gives besides additional information regarding the early history of its invention, some account of it is subjoined.

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[1] "Excerpta ex viri clarissimi Dionysii Papini, Mathematum in Academia Marpurgensi Professoris Publici, litteris ad . . . . . de Novo Pulveris Pyrii usu."

[2] Pp. 497-501. This periodical was commenced in 1682, under the auspices of Papin's friend Leibnitz.

The proposal to utilize the force of gunpowder in the arts, made in the Dutch *Nouvelles* for the month of May, 1687, he states, had been so much approved of by the Most Serene Prince, the Landgrave of Hesse, that his Highness had thought the subject worthy of discussion with him during a sojourn he had lately made at Cassel. He had constructed a small machine, which, though it did not equal in its effects the other described in the *Nouvelles*, and shown to Lord Colbert, was nevertheless sufficient to exhibit what might be expected from an engine of this kind; it contained besides some considerable improvements. He therefore thought it worth while to make it known to the literary world, in order that many minds might be directed to the work of perfecting the invention, and the public might the sooner derive benefit from it.

A A (Fig. 14), is a tube uniform throughout, sixteen inches high, and five inches in diameter. B B, a piston exactly fitting the tube, and about two inches in height. C C, a tube fastened to the upper side of the piston, about four inches in height, and almost equal in diameter to the piston in order to present a free passage to the flame. D D, D D, an aperture in the middle of the piston, the diameter of which should be such that the flame shall have as large a passage through as it has between the two tubes C C, F F. E E, a valve placed over this aperture, the diameter

of which should be such that it exactly covers the aperture and no more. F F, a light metal tube, three inches high, fastened to the upper surface of the valve E E, and having almost the same diameter: its

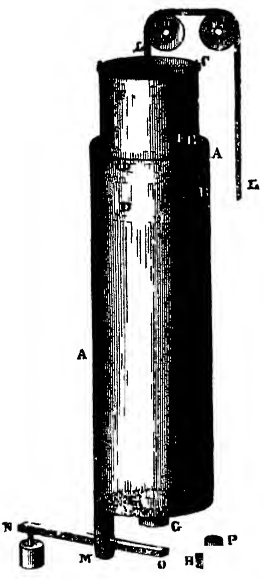

FIG 14.—PAPIN'S GUNPOWDER AND AIR ENGINE, 1687

use is to fill part of the tube C C, the flame occupying the rest of it, in order that the tube C C, during the operation, may remain vacuous, and there may be no danger of any air entering the apperture D D before the valve closes. G G, a little tube open on

both sides, thirteen lines in height and diameter, inserted into and secured to the bottom of the pump A A. H, P, two metal cases fastened to one bottom,—the inner, P, being twelve lines in length and nine in diameter,—the outer, H, being six lines in length and eighteen in diameter: the inner for containing powder, the outer, water. The mode of securing the cylinder is not shown in the figure.

A small piece of kindled match together with fifteen grains of gunpowder is then put into the case P, which is inserted into the tube G G, which passes down between P and H to the common bottom, and makes an air-tight joint by means of water and leather contained in H. It is there kept in position by means of the weighted lever N O.

The action of the machine it is unnecessary to follow. Papin states that it was found by experience that the cylinder was never completely emptied of air, but there always remained about a fifth part, which caused the machine only to produce one-half of the effect due to the atmospheric pressure.

After recounting the points in which he considered the above machine superior to the one invented by Huyghens and shown to Colbert, he proceeds to remark that as no account of the other was published in the journals at the time,[1] people may think that

[1] Papin having been in Italy at the date of Hautefeuille's publication (in 1682), was probably unacquainted with it.

his statements about it are made rashly and without foundation. He therefore thinks it right to state that at that time he had the honour to reside in the royal library with the illustrious Lord Huyghens, and aided him in the undertaking; and he was the person who showed the experiments in the presence of Lord Colbert, and therefore ought to know all about it.

In the same volume of the *Acta Eruditorum* (anno 1688), Papin shortly afterwards published an account of his method of transmitting power to a distance by the rarefaction of the air in pipes;[1] but as this invention has already been described, we pass on to his celebrated memoir of August, 1690, which appeared in the same periodical,[2] and in which the production of a vacuum under a piston by the *condensation of steam*, was suggested for the first time. This memoir, as is well known, is entitled "A New Way to obtain very great Motive Powers at small cost."[3]

After referring to the inconveniences attending the attempts to obtain a vacuum by means of gunpowder,

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[1] "Additamentum ad Disquisitionem Dn. Papini de novo pyrii pulveris usu, mense proximo Septembri in Actis hisce, pag. 497, exhibitam: De usu tuborum prægrandium ad propagandam in longinquum vim motricem fluviorum, &c. Communicatum a laudato, Dn. Papino," pp. 643-646.

[2] *Acta Eruditorum*, anno 1690, pp. 410-414.

[3] *Nova Methodus ad vires motrices validissimas levi pretio comparandas.* A translation of this paper has been published by Mr. Muirhead in his *Life of Watt*, 2nd ed., p. 136; and the original Latin, accompanied by a translation, in his *Mechanical Inventions of James Watt*, Vol. III., p 139.

and stating that trials had long been made to produce a perfect vacuum by this means, but to no purpose, he proceeds to say: "I therefore endeavoured to attain the same end in another way: and since it is a property of water, that a small quantity of it turned into vapour by heat has an elastic force like air, but upon cold supervening is resolved again into water, so that no trace of the said elastic force remains: *I at once saw that machines could be constructed, in which water, by the help of a moderate heat, and at little cost, might produce that perfect vacuum which could by no means be obtained by the aid of gunpowder.* Among various constructions which might be made for this purpose, the following seemed to me most suitable:

"A A (Fig. 15), is a tube of uniform diameter throughout, close shut at the bottom; B B is a piston fitted to the tube; D D a handle fixed to the piston; E E an iron rod movable round an axis F; G a spring pressing the cross-rod E E, so that the said rod must be forced into the groove H as soon as the piston with the handle has arrived at such a height as that the said groove H appears above the lid I I; L is a little hole in the piston, through which the air can escape from the bottom of the tube A A, when first the piston is forced into it. The use of this instrument is as follows:—A small quantity of water is poured into the tube A A, to the depth of three or four lines; then the piston is inserted and forced down to the

bottom, till a portion of the water previously poured in comes through the hole L; then the said hole is closed by the rod M M. Next the lid I I, pierced with the apertures requisite for that purpose, is put on, and

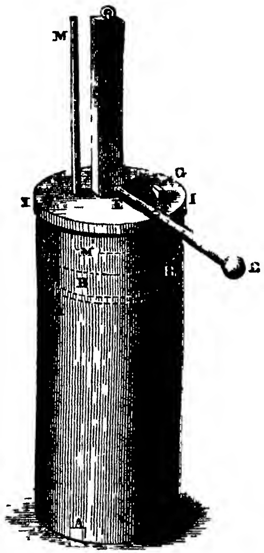

FIG. 15.—PAPIN'S STEAM AND AIR ENGINE, 1690.

a moderate fire being applied, the tube A A soon grows warm (being made of thin metal), and the water within it, being turned into steam, exerts a pressure so powerful as to overcome the weight of the atmosphere and force up the piston B B, till the groove

H of the handle D D appears above the lid I I, and the rood E E is forced, with some noise, into the said groove by the spring G. Then forthwith the fire is to be removed, and the steam in the thin metal tube is soon resolved into water, and leaves the tube entirely void of air. Next, the rod E E being turned round so far as to come out of the groove H, and allow the handle D to descend, the piston B B is forthwith pressed down by the whole weight of the atmosphere, and causes the intended movement; which is of an energy great in proportion to the size of the tube."

He states that his tube was only two-and-a-half inches in diameter, and raised sixty pounds: and that one minute's time was sufficient for a moderate fire to drive the piston to the top. He afterwards suggested making a vacuum in a number of tubes in succession, each to be removed for use as it was emptied, having, he said, found it better to bring the tubes to the fire than the fire to the tubes. In this way, by means of a strong fire, he was able to empty a tube of air in fifteen seconds.[1]

From the date of the above proposal of Papin, the engine enters upon a new phase of its history. It ceased to be a gunpowder-and-air engine, and now became a *steam-and-air* engine. Papin's new invention demonstrated a great principle, but he produced no

[1] *Fasciculus Dissertationum de novis quibusdam Machinis*, &c., authore Dionysio Papin, Marburgi Cattorum, 1695, p. 63.

useful machine. He proposed to apply this power to draw water, or ore, from mines; to discharge iron bullets to a great distance; to propel ships against the wind (by an arrangement of paddle-wheels which he describes); and to a multitude of other similar purposes. It does not appear, however, that he constructed any successful engines.

An account of the above invention, as also of his method of transmitting the power of a water-wheel to a distance by exhausting air through pipes, was included in a small treatise published by Papin, both in Latin and French, at Marburg and Cassel respectively, in the year 1695.[1] His later history will be referred to hereafter; for the present we must leave him in order to follow the course of events in England.

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[1] *Fasciculus Dissertationum de novis quibusdam Machinis*, &c., authore Dionysio Papin, Marburgi Cattorum, 1695. *Recueil de diverses Pièces touchant quelques nouvelles Machines*, Cassel, 1695. They were also published in a treatise entitled *Traité de plusieurs nouvelles Machines et Inventions Extraordinaires sur différents sujets*, par M. D Papin, Dı en Med. &c , Paris, 1698. The latter publication is not mentioned in Mr. Muirhead's lists of the works of Papin. [*Life of Watt*, 2nd ed., p. 525 ; *Mechanical Inventions of Watt*, Vol. III., p. 155.]

CHAPTER V.

THOMAS NEWCOMEN BECOMES ACQUAINTED WITH THE PROPOSALS OF PAPIN AND CONTEMPLATES THE CONSTRUCTION OF AN ATMOSPHERIC ENGINE.—HE IS ANTICIPATED BY CAPTAIN SAVERY, WHO OBTAINS A PATENT FOR AN ENGINE FOR RAISING WATER BY FIRE.

So far we have traced the progress of the atmospheric engine—the parent of the modern steam engine—in the hands of philosophers. We have seen them well aware of the practicability of deriving a new motive power from the atmospheric pressure. We have followed their attempts to embody in a machine the principles which philosophy had expounded. Their efforts, however, were attended with very limited success; no really useful engine had resulted from them. But if philosophers had failed to solve the problem themselves, their essays had the effect of arousing attention to the subject from men of another class—

workers in brass and iron, artisans and mechanics—and put them in possession of the scientific principles upon which a new motive engine might be constructed. Science joined hands with Art; out of their union was evolved Newcomen's admirable engine.

Thomas Newcomen was a native of Dartmouth, in Devon. Of his personal history little has been preserved. At what precise date, or under what circumstances, he began to study the subject of constructing an atmospheric engine, we are not informed. Of the various projects which had been brought forward by Papin for employing the atmospheric pressure as a motive power, no account had been published in England previous to a brief notice of them in the *Philosophical Transactions* for the year 1697, in a review of the little book published on the Continent by Papin, as above mentioned, in 1695.[1] It is evident that in some way Newcomen had become acquainted with them. When he first comes before us, we find him in communication with Dr. Hook upon the subject. "There are to be found among Hook's papers, in the possession of the Royal Society," says Dr. Robison, "some notes of observations, for the use of Newcomen, his countryman, on Papin's boasted method of transmitting to a great distance the action of a mill by means of pipes. . . . . It would appear from these notes that Dr. Hook had dissuaded Mr. Newcomen from erecting a

[1] See *Phil. Trans.* No. 226, p. 481.

machine on this principle, of which he had exposed the fallacy in several discourses before the Royal Society. One passage is remarkable: 'Could he (meaning Papin) make a speedy vacuum under your second piston, your work is done.'"[1]

To what exact date these notes belong we cannot tell, but we can assign limits to the period during which they must have been made, viz., between 1687, the year when Papin proposed his novel plan of working an atmospheric engine at a distance by exhausting air through pipes, and March 1702-3, the date of Dr. Hook's death. The statement of a contemporary writer, however, enables us to limit still further the period in which Newcomen first began to devote his attention to the subject. "I am well informed," says Switzer, "that Mr. Newcomen was as early in his invention as Mr. Savery was in his, only the latter being nearer the Court had obtained his patent before the other knew it; on which account Mr. Newcomen was glad to come in as a partner to it."[2] Savery obtained his patent on the 25th of July, 1698, from which it follows that Newcomen had already been

[1] *A System of Mechanical Philosophy*, by John Robison, LL.D., with Notes, by David Brewster, LL.D., Edinburgh, 1822, Vol. II., p. 57. It has been ascertained by personal inquiry at Burlington House that it is not at present known whether these papers of Dr. Hook are still in the possession of the Royal Society.

[2] *An Introduction to a General System of Hydrostaticks and Hydravlicks*, &c., by Stephen Switzer, London, 1729. Vol. II., p. 342.

contemplating the construction of an atmospheric engine previous to this time.[1]

For the next twelve years there appears to be no reliable information regarding Newcomen. Whether the success of Savery's first engines led him for a time to abandon his own schemes and adopt those of Savery, or whether he spent this time in brooding over his own invention, and only joined Savery after having succeeded in overcoming all its difficulties, we know not. The first hypothesis, however, seems most in accordance with the statement of Switzer quoted above, and would readily account for the amicable relationship which appears to have all along existed between the two inventors.[2]

It seems certain at all events that so long as Savery's

[1] The fact of Newcomen having begun to turn his attention to the atmospheric engine, apparently about 1697 or 1698, renders it highly probable that his doing so was occasioned by the publication of the account of Papin's proposals in the *Philosophical Transactions*.

[2] Papin regarded Savery's method of raising water as superior to the plans proposed by himself before, and adopted it, as will be seen hereafter. It seems probable that Newcomen did the same for a time.

This supposition receives some support from the following account of the origin of Newcomen's invention, which, though containing some errors, may nevertheless not be altogether incorrect:

"Mr. Harris, in his Lex[icon] Tech[nicum] published a draught of Mr. Savery's engine, and gave an account of this power and machine, which, falling into the hands of Mr. Newcomen, of Dartmouth, he formed anew the model of an engine by it, fixed it in his own garden, and soon found out its imperfections. When he had done this he obtained a patent," &c. [Shaw's *History of Staffordshire*, Vol. II., P. I., p. 120.]

engines promised to be successful, Newcomen's invention remained in the background, and afterwards, when experience had shown their weaknesses and defects, Newcomen's engine was brought forward as an improvement of Savery's, and under the protection of his patent.

Though Savery's engine cannot be regarded as a link in the development of the atmospheric engine, as it belonged to a wholly different class of machines, yet there is reason to believe that Newcomen obtained some valuable hints from it. For this and other considerations, it is desirable to present here some account of this engine and its inventor.

Thomas Savery is stated to have been born at Shilston, in Devon, about 1650, and to have been educated as a military engineer. He was of a decidedly mechanical turn of mind, and possessed of great ingenuity. He is frequently referred to as Captain Savery.[1] Switzer, who tells us he had the honour to be well acquainted with him, speaks of him as "a most noted engineer, and one of the commissioners of the sick and wounded."[2] The latter part of his life appears

[1] By some writers Savery is stated to have been a mine-captain, and by others a sea-captain, but it seems certain that he was neither.

[2] *Hydrostaticks and Hydraulicks*, Vol. II., p. 325. If this be the passage referred to by Stuart in his *Anecdotes of Steam Engines*, Vol. I., p. 102, the word "seamen" is there added by mistake, as it does not occur in Switzer.

to have been devoted to a large extent to the introduction of his engine for raising water by fire.

Long before the time of Savery, the efforts of the ingenious had been directed to the construction of a species of fountain, in which water might be made to spout upwards by the expansive force of steam. The machines which had been produced were, however, rather objects of curiosity than of any practical utility.[1] In the hands of Savery, the engine for the first time promised to become really of some service for raising water, and the mechanism which he invented for the purpose, was both very complete and efficient, so far as the principle of the machine would admit of it.

His engine is first heard of in the year 1698. Its construction, and the mode of working it, will be understood from the following description :—

A (Fig. 16), are two furnaces, of which B 1, B 2, are the fire-places, and C the chimney.

[1] The claims put forward on behalf of the Marquis of Worcester have been much overstated. It has been *assumed* that the engine, the monopoly of which was secured to the Marquis by an Act of Parliament, in 1663, was the apparatus for raising water by fire, which is described in the 68th proposition of his *Century of Inventions*. The terms of the Act, however, would lead to the inference that it refers to the engine described in the 100th proposition. The supposition that the 68th and the 100th propositions of the *Century* refer to one and the same machine is pure and unwarranted hypothesis. Mr. Hook went to see the Marquis of Worcester's "water-commanding engine," in 1667, and described it to Mr. Boyle as a perpetual motion fallacy [See Dircks' *Life, &c., of the Marquis of Worcester*, London, 1865, p. 293.]

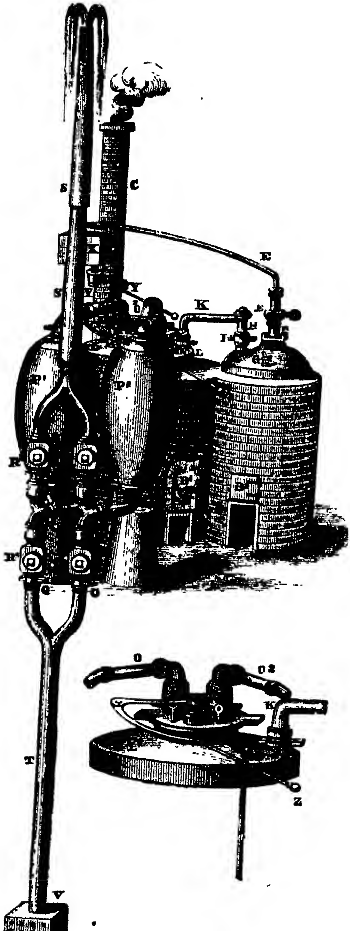

FIG. 16.—SAVERY'S ENGINE FOR RAISING WATER BY FIRE, 1702.

In the two furnaces are two vessels called by Savery *boilers ;* a larger one L, and a smaller one D.

Each boiler has a *gauge-pipe,* viz., G going within eight inches of the bottom of the little boiler, and N half-way down the great boiler.

In preparing to work the engine, G and N were unscrewed, and water was poured in at the holes till the small boiler was quite full, and the great boiler two-thirds full. A fire was then kindled in the furnace B1, and the water in L made to boil. On sufficient steam being raised, Z, the handle of the *regulator* or steam-valve, was pushed away (say) as far as it would go, so as to open a passage through the steam-pipe O1, into the receiver P1, and the steam rushing in drove out the air before it, forcing it up into the force-pipe, through the clack R1. As soon as the receiver P1, was emptied of air, the handle of the regulator was then pulled as far as it would come, so as to close the communication between that receiver and the boiler, and at the same time to open a passage for the steam into the other receiver, P2. While P2 was being emptied of air, cold water was poured on to P1, and a vacuum produced within it by the condensation of the steam. Thereupon the water in the reservoir was driven up the sucking-pipe T, through the clack R3, and the receiver P1 filled with it; the closing of the clack preventing the escape of the water back into the reservoir.

The receiver P2 having in the meantime become emptied of air, the handle of the regulator was again pushed away, so as to close the communication between it and the boiler, and to admit the steam into P1, where pressing upon the surface of the water contained in it, it drove it up through the passage Q, R1, Q, into the force-pipe S, and discharged it out at the top.

In the same manner the receiver P2 was filled and emptied of water, and by the alternate action of the two receivers, a constant stream could be kept issuing at the top of the force-pipe.

As soon as the engine commenced to work, the water filled the cistern X, and from this a supply was obtained for the *condensing-pipe* Y.

The pipe E was used to convey water from the force-pipe into the little boiler D. The object of this boiler was to replenish the great boiler with water when necessary. To effect this, the cock E having been closed, a fire was lighted in the furnace B2, and sufficient steam was raised to force the water contained in the small boiler up the pipe H through K into the great boiler, until the water got below the level of the pipe H, which became known to the attendant by the rattling of the clack I.[1]

[1] An account of Savery's engine appeared in the *Philosophical Transactions*, anno 1699, No. 253, p. 228. It is mentioned in *A Familiar Discourse or Dialogue concerning the Mine-adventure*, printed at London in 1700, p. 50. Savery published a description of his engine in 1702, in a treatise entitled *The Miners' Friend, or an Engine to raise*

All the vessels of the engine were made of the best hammered *copper;* the clacks, boxes, miter-pipe, regulator, and cocks were all of *brass;* the water-pipes were of *wood*, as was usual at that date. It will be observed, from the description given above, that all the movements necessary to keep the engine working required to be performed by hand.

Savery's engine promised at first to be a great success. "I have heard him say myself," Switzer tells us, "that the very first time he played it, was in a potter's house at Lambeth, where though it was a small engine, yet it forced its way through the roof and struck up the tiles in a manner that surprised all the spectators."[1] We next hear of him exhibiting a small model before the king at Hampton Court, to His Majesty's seeming satisfaction of the power and use of it.[2] This appears to have been previous to the date of the patent for the engine, which he obtained, as already stated, on the 25th of July, 1698.[3] The patent is described in the *Chronological Index* as follows:—

Water by Fire described, and the manner of fixing it in Mines, with an account of the several other uses it is applicable unto; and an answer to the objections made against it, by Thomas Savery, Gent. London, 1702. Another account of it appeared in 1704, in Harris's *Lexicon Technicum*, 1st ed., see the word "Engine." *The Miners' Friend* was reprinted at London in 1829, and again [by George E. Eyre and William Spottiswoode] in 1858.

[1] *Hydrostaticks and Hydraulicks*, Vol. II., p. 325.

[2] *The Miners' Friend*, in the dedication to the king.

[3] No. 356.

"A grant to Thomas Savery, gentleman; of the sole exercise of a new invention, by him invented, for raising of water, and occasioning motion to all sort of mill-works, by the impellent force of fire, which will be of great use for draining mines, serving towns with water, and for the working of all sorts of mills where they have not the benefit of water, nor constant winds; to hold for fourteen years; with usual clauses."

On the 25th of April, 1699, Savery obtained a private Act of Parliament, extending the patent privilege twenty-one years further, or for a total term of thirty-five years.[1]

A short time afterwards, viz., on the 14th of June, 1699, at the request of some of the members of the Royal Society, he exhibited a small model of his engine before the Society, who approved of it. This exhibition is called by Savery, "its first appearance in the world," and the notice of it contained in the *Philosophical Transactions*,[2] is referred to by him as "publishing it to the world." [3]

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[1] The Act of Parliament is published along with the specification of the patent. It is also printed in Muirhead's *Mechanical Inventions of James Watt*, Vol. III., p. 125. Mr. Weld, in his *History of the Royal Society* [Vol. I., p. 358], states that "the certificate granted to Savery by the [Royal] Society was the means of his procuring a patent from the crown for the manufacture of steam-engines." This is obviously quite erroneous. Switzer too appears to have thought that the exhibition of the engine before the Royal Society was anterior to the date of the patent. [*Hydrostaticks and Hydraulicks*, Vol. II., p. 325.]

[2] No. 253, p. 228.

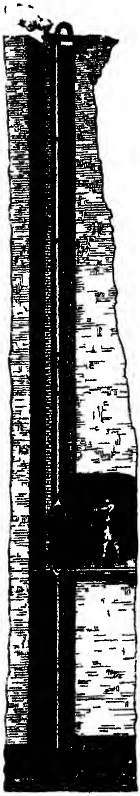
[3] The *Miners' Friend*, Dedication to the Royal Society.

He appears to have built several engines very soon after this date. In his dedication to the king prefixed to his treatise entitled *The Miners' Friend*, which was published in 1702, he speaks of his invention being now fully completed and put in practice with repeated success and applause.

The engine however did not fulfil the sanguine expectations entertained at first regarding it. He erected several which raised water very well for gentlemen's seats, but could not succeed for mines, nor in supplying towns, where the water was to be raised very high and in great quantities.[1]

Savery had expected great things from the introduction of his engine as a mine-draining machine. "I do not doubt," he says, "but that in a few years, it will be the means of making our mining trade, which is no small part of the wealth of this kingdom, double if not treble to what it now is. . . . For the far greater part of our richest mines and coal-pits, are liable to two grand inconveniences, and thereby rendered useless, viz., the eruption and excess of subterraneous waters, as not being worth the expense of draining them by the great charge of horses, or hand labour.

[1] *A Course of Experimental Philosophy*, by J. T. Desaguliers, LL. D., F.R.S., Vol. II., p. 466. The first edition of the second volume of the above work was published at London in 1744, and the third edition in 1763. The pagination appears to be the same in both.



7 —SAVERY'S ENGINE IN A MINE, 1702.

Or, secondly, fatal damps, by which many are struck blind, lame, or dead, in these subterraneous cavities, if the mine is wanting of a due circulation of air Now, both these inconveniences are naturally remedied by the work of this engine, of raising water by the impellent force of fire "[1]

In applying this engine to the draining of a mine, it was necessary that it should be built in a recess in the shaft, within twenty-six or twenty-eight feet of the level of water to be raised (Fig 17). The idea of utilizing the furnace of the engine for ventilating the mine was a novel one. It appears to be the first allusion we have to the use of a ventilating furnace placed *underground.* Furnaces at the surface had been applied to ventilate coal mines at Liège, in Belgium, for half a century previous to this date[2] As yet they

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[1] *The Miners' Friend*, pp. 33-4.

[2] *Philosophical Transactions of the Royal Society of London*, anno 1665. No 5, p. 79.

seem to have been unknown in the collieries of this country. The earliest notice of the use of fire to ventilate the collieries in the Newcastle-on-Tyne district, known to the writer, is dated 1732.[1]

Notwithstanding the benefits which Savery alleged would result to the miners from the adoption of his engine, he failed to induce them to take it up. It does indeed appear from his own statement, that he had built one of his engines in a coal-pit previous to the publication of his book in 1702. "The coals used in this engine," he says, "are of as little value as the coals commonly burned on the mouths of the coal-pits are. For an engine of a three-inch bore or thereabout, working the water up sixty feet high, requires a fire-place of not above twenty inches deep, and about fourteen or fifteen inches wide, which will occasion so small a consumption, that in a coal-pit it is of no account, *as we have experienced.*"[2] Again in speaking of his engine producing a circulation of the air in a mine, he adds, "*This I have tryed,* and know to be true."[3] We have no special mention of his ever having built another in a mine. "Savery," says M. Arago, "entitled his work *The Miners' Friend*, but the miners

[1] *View of the Coal Trade of the North of England*, by Matthias Dunn, Newcastle-upon-Tyne, 1844, p. 42. See also *The Archæology of the Coal Trade*, by T. John Taylor, in the *Transactions of the Archæological Institute* of Great Britain and Ireland, anno 1858, Vol. I, p. 201.

[2] *The Miners' Friend*, pp. 35-6. [3] *Ibid*, p. 38.

seemed scarcely to appreciate the important compliment he paid them. With one solitary exception, none of them ordered his engines."[1]

In what district the above-mentioned engine was erected we are not informed by M. Arago, but it is stated that a fire engine was employed very early at a colliery near Coventry,[2] in the Warwickshire coal-field, which was perhaps the engine referred to. This coal district is the nearest to the metropolis.

Among the causes which would prevent the miners from employing Savery's engine, may be mentioned its limited range, and the danger of explosion attending its working. The greatest height to which it could raise water with safety, was not more than from 60 to 80 feet, so that for a mine of 50 or 60 fathoms[3]—a

[1] *Life of James Watt*, by M. Arago, 2nd ed. Edinburgh, 1839, p. 36. It must be admitted, however, that Switzer speaks as if a number of Savery's engines had been built at collieries. See his *Hydrostaticks and Hydraulicks*, Vol. II., pp. 327-328.

[2] *The Archæology of the Coal Trade*, by T. John Taylor, *ut supra*, p. 194, note. Mr. Taylor gives no authority for the statement, but it appears to the writer that this is probably the fire engine mentioned in Farey's *Treatise on the Steam Engine*, p. 155 (note), where it is supposed to have been one of Newcomen's engines. The fact of its having no working gear seems clearly to point to its being one of Savery's engines. A considerable amount of confusion prevails as to this engine, which is rendered more perplexing by misquotations from Desaguliers. Regarding the fire engine mentioned by Farey, it may be remarked that it is not stated to have been at Griff, but near Coventry. There were many collieries between Griff and Coventry at this date.

[3] *i.e.* 300 or 360 feet; a fathom being equal to six feet

depth which had already been reached in some districts at this time—no less than four or five engines would have been required, one delivering to the other. Such a complication of engines was not to be thought of. But in any case where the water was required to be raised to a considerable height, there was great danger of the boiler bursting, on account of its not being provided with any species of safety-valve.

We have accounts of several engines erected by Savery. The only successful ones were in situations where the work required to be performed was very light. Of these the engine built at Cambden-house was regarded as one of the best. Bradley, writing in 1718, speaks of it in the following terms:—

"Supposing the situation of a house or garden to be a considerable height above any pond, river, or spring, and that it has at present no other conveniency of water than that which is brought continually by men or horses to it. In this case the wonderful invention of the late Mr. Savory, F.R.S., for raising water by fire, will not only supply the defect by flinging up as much water as may be desired, but may be maintained with little trouble and very small expense.

"It is now about six years since Mr. Savory set up one of them for that curious gentleman Mr. Balle, at Cambden House, Kensington, near London, which has succeeded so well that there has not been any want of water since it has been built." [1]

Bradley then proceeds to give a design and description

[1] *New Improvements of Planting and Gardening*, by Richard Bradley, F.R.S. The third part, 2nd ed., London, 1718, p. 175.

of the above engine (Fig. 18), which he regarded as the truest proportioned of any about London. From this it appears that the engine had only one receiver, and raised the water 58 feet; and that the prime cost of such an engine was about 50*l.* The same engine is described by Switzer.[1]

The attempts of Savery to apply his engine to heavy work, however, resulted in failure. Dr. Wilkes informs us that—

"Mr. Thomas Savary (the original inventor of the steam-engine) set one of these engines down about the year 17— in the liberty of Wednesbury, [in Staffordshire], near a place called then the broad waters, which is now dry land again. For this place being low ground, the water rose so hastily many years ago, and in such quantities from the coal-pit, that it covered some acres of land, buried many stacks of coals that were on the bank, and so continued till drained again about fifteen or twenty years ago. . .

"The engine thus erected could not be brought to perfection, as the old pond of water was very great, and the springs very many and strong that kept up the body of it; and the steam when too strong tore it all to pieces; so that after much time, labour, and expense, Mr. Savary was forced to give up the undertaking, and the engine was laid aside as useless; so that he may be said to have discovered a power sufficient to drain any kind of mine, but could not form an engine capable of working and making it useful."[2]

Another engine, erected at York Buildings, to raise water from the Thames for supplying the western parts

[1] *Hydrostaticks and Hydraulicks*, Vol. II., p. 328.

[2] *The History and Antiquities of Staffordshire*, by the Rev. Stebbing Shaw, B.D., F.A.S., London, 1798, Vol. II., P. I., p. 85.

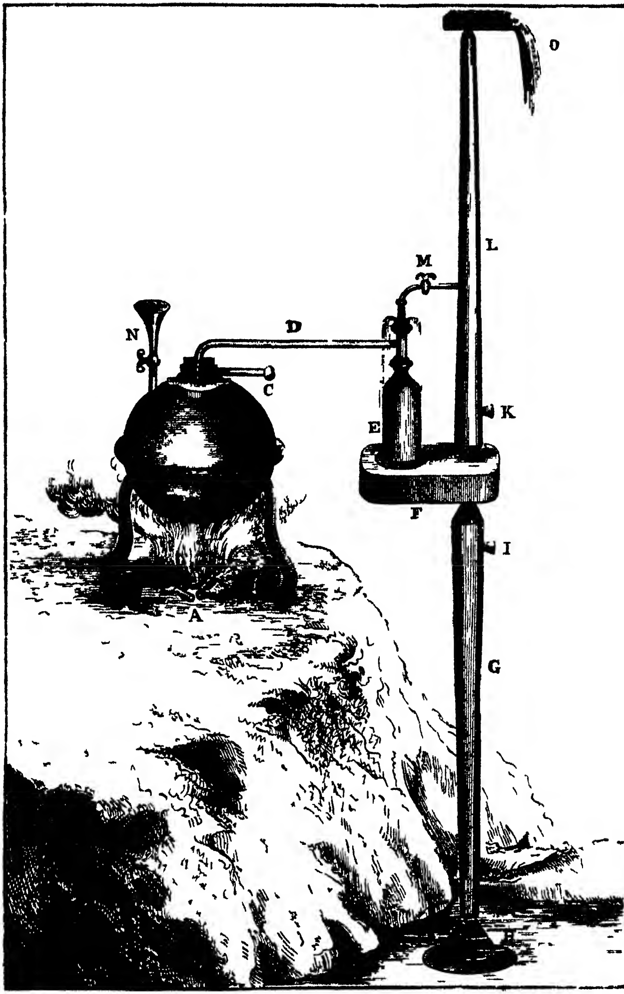

FIG 18 —ENGINE WITH ONE RECEIVER, BUILT BY SAVERY AT CAMBDEN HOUSE, KENSINGTON, ABOUT 1712

of London, was equally unsuccessful. "I have known Captain Savery at York Buildings," says Dr. Desaguliers, "make steam eight or ten times stronger than common air, and then its heat was so great that it would melt common soft solder; and its strength so great as to blow open several of the joints of his machine: so that he was forced to be at the pains and charge to have all his joints soldered with spelter or hard solder."[1]

Regarding the same engine Bradley remarks as follows:—

"This particularly I observed[2] in the attempt of raising water at York Buildings by the engine for raising water by fire, where Captain Savory, the inventor of it, was concerned in the setting of it up. That gentleman, though he had before set up his engines with good success in several places, especially at Cambden House, near Kensington, was not content with the plainness of them when he undertook so great a work as furnishing the publick with water, but doubled every part in the York Buildings engine, and by that made it impracticable for one man to work it; and it was liable to so many disorders if a single mistake happened in the working of it, that at length it was looked upon as a useless piece of work and rejected. And after this it had as bad success from others who endeavoured to mend it, or improve it, as they called it, by altering the Captain's first methods; so that these, in some measure, lost the credit which his first engines had got him."[3]

[1] *Experimental Philosophy*, Vol. II., pp. 466-7.

[2] Viz., that engines consisting of many parts were frequently out of order.

[3] *Ten Practical Discourses concerning Earth and Water*, &c., by R. Bradley, F.R.S., Westminster, 1727, p. 33. The engine at Cambden

We shall conclude our remarks on the subject of Savery's engine, with the following passage containing a curious allusion to the new invention, taken from a treatise on coal-mining as practised in the Newcastle-on-Tyne district, entitled *The Compleat Collier*, which was published in the year 1708 :—

"If it would be made apparent," says this writer, "that as we have it noised abroad, there is this and that invention found out to draw out all great old waists, or drowned collieries, of what depth soever, I dare assure such artists may have such encouragement as would keep them their coach-and-six, for we cannot do it by our engines, and there are several good collieries which lye unwrought and drowned for want of such noble engines or methods as are talk'd of or pretended to, yet there is one invention of *drawing water by fire*, which we hear of, and perhaps doth to purpose in many places and circumstances, but in these collieries hereaway, I am affraid there are not many that dare venture of it, because *nature* doth generally afford us too much sulpherous matter, to bring more fire than within these our deep bowels of the earth,[1] so that we judge cool inventions of suction or force, would be safest for this our concern, if any such could be found that would do so much better, and with more expedition than what is done generally here."[2]

House was erected, as has been seen, about 1712, and it appears from the above account that the York Buildings engine was of a later date. It would thus seem that Savery adhered to his own invention, even after the successful introduction of Newcomen's engine.

[1] The common depth of the pits in the Newcastle-on-Tyne district at this date was from twenty to thirty fathoms; a few were from fifty to sixty fathoms. [*Bald's View of the Coal Trade of Scotland*, p. 8.]

[2] *The Compleat Collier: or the Whole Art of Sinking, Getting, and Working Coal-mines, &c., as is now used in the Northern Parts, especially about Sunderland and Newcastle*, by F. C., London, 1708. Reprinted at Newcastle in 1846, p. 23.

CHAPTER VI.

PAPIN AT CASSEL. — HIS EXPERIMENTS WITH HIGH-PRESSURE STEAM.—CLOSING YEARS OF HIS LIFE.

WHILE Savery was engaged in erecting his engines in different parts of England, with varied success, some attempts were made by Papin on the Continent to construct engines on the same principle.[1] How the latter came to direct his attention to engines of the steam-fountain class, will appear from the following brief account of the remaining portion of his life.

Scarcely had Papin been settled, as professor of mathematics at Marburg, before he began to desire a change of position. This he at length obtained, in 1695, when his patron, the Landgrave of Hesse, removed him from Marburg to Cassel.[2] Here he was employed by the Landgrave in superintending and carrying out various engineering and other works.

[1] *Vie de Papin*, par L. de la Saussaye et A. Pean, Vol. I., p. 213.
[2] *Ibid.* pp. 171, 197.

Among these was a project for the establishment of a manufactory for the making of glass, and the preliminary experiments made with a small furnace in the year 1697 having proved successful, in the beginning of the following year Papin was afforded an opportunity of preparing to carry out the scheme on a more extensive scale. In the midst of the preparations, however, the work was interrupted. In a letter to his friend Leibnitz, dated 10th April, 1698, Papin informs him that the large furnace which had been constructed for melting the glass, had been taken to make certain "large iron vessels very useful for producing great effects by the force of fire."[1] This is the first allusion in the correspondence between Papin and Leibnitz, to the new projects which the former now entered upon. The sudden change of plan was brought about by an order from the Landgrave, under whose directions Papin forthwith turned his attention to the construction of an engine after the principle of Savery's, which the Landgrave was desirous of applying to raise the brine out of his salt mines of Allendorf. On the 28th of August following, Papin announced to Leibnitz that he had succeeded in raising water by the force of steam to a height of 70 feet.[2] Papin himself disclaimed any share in the merit of the invention; he was acting under command; the idea came from the Landgrave.

[1] *Vie de Papin*, par L. de la Saussaye et A. Pean, Vol. I., pp. 201, 203. [2] *Ibid.* p. 208.

The action of the machine, however, was slow and irregular, and its use was not continued.[1]

On the 8th of June, 1699, Papin informed Leibnitz that he had heard from Dr. Slare that a short time previously a committee of the English Parliament had approved of a machine for raising water by the force of fire. The Landgrave had been dissatisfied with the plan which had been adopted for supplying his castle[2] with water from the river Fulda, and on hearing of the success of this machine he directed Papin to construct one for this purpose. The building of an engine was accordingly commenced on the edge of the Fulda, but the machine having been destroyed by a breaking up of the ice on the river, the experiment proved abortive and the scheme was postponed indefinitely[3]

In his treatise published in 1707,[4] Papin tells us in reference to these his experiments, that having been discontinued they might have remained in oblivion, had not Leibnitz, in a letter dated January 6th, 1705, sent him a drawing of Savery's engine, and asked his opinion of it. He states that the machine he had been endea-

[1] *Vie de Papin*, par L. de la Saussaye et A. Pean, Vol I. p. 217.

[2] Wilhelmshohe.

[3] *Vie de Papin*, par L. de la Saussaye et A. Pean, p. 209

[4] *Nouvelle manière pour élever l'Eau par la force du Feu mise en lumière.* Cassel, 1707. The same treatise appears to have been published at Frankfort in Latin. *Ars nova ad aquam Ignis adminiculo efficacissime elevandam.* Frankfort, 1707. See also the *Acta Eruditorum* for the year 1707.

vouring to construct was founded on the same principle as the English one. The drawing sent by Leibnitz having been brought under the notice of the Landgrave, Papin was again directed to proceed with the construction of a machine to raise water for turning a corn-mill.[1] The engine which he devised is that described in his treatise of the year 1707 (Fig. 19). Departing in a large

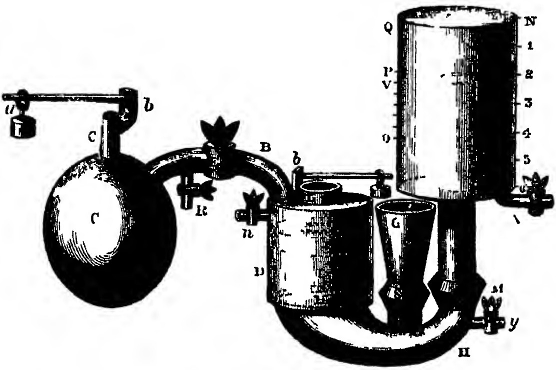

FIG. 19.—PAPIN'S MODIFICATION OF SAVERY'S ENGINE, 1707.

measure from Savery's design, Papin made his receiver of a cylindrical form, with a view to the employment of a diaphragm floating upon the top of the water, to lessen the condensation of the steam. The machine thus constructed was never applied.[2] The advantage of the sucking limb was lost by Papin's proposed arrangement, and instead of being an improvement

[1] *Vie de Papin.* par L. de la Saussaye et A. Pean, Vol. I., p. 21.
[2] *Ibid*, p. 222.

upon Savery's method, it was in many respects greatly inferior to it.

The closing years of Papin's life were beset with misfortunes. Among the many schemes which occupied his attention, was a method of employing steam of a very high pressure, in lieu of gunpowder, for throwing projectiles. An experiment which he made resulted in a serious explosion, by which a large portion of the workshop was destroyed and several men mortally wounded.[1] Papin had for some time contemplated leaving Cassel. This accident precipitated his departure.

He had constructed a small boat with paddle-wheels, with the intention of ultimately propelling it by means of a steam engine of some kind.[2] He was now desirous to sail down the river in his boat, his intention being to put it on board of a ship and proceed with it to London. But the jurisdiction of the Landgrave terminated at the confluence of the Fulda with the Weser. Beyond this point he could not proceed without obtaining the permission of the river authorities. After spending some time in trying in vain to procure the licence, Papin at length resolved to face the difficulties that lay in his path. Launching his boat on the Fulda

[1] *Vie de Papin*, par L. de la Saussaye et A. Pean, Vol. I., p. 229.

[2] It has been stated that Papin intended to raise water on to a water wheel to give motion to the paddle-wheels, but this seems highly improbable. It seems more reasonable to suppose that he designed to carry out the process which he had published in 1690. [See *ibid.* p. 170.]

he arrived at the limits of the Hessian territory. Here his progress was obstructed by the boatmen; his little boat was drawn out of the river and broken to pieces on the bank.[1]

In the end of the year 1707 Papin at length arrived in London for the last time. Early in the following year we find him endeavouring to interest the Royal Society in his steam navigation projects, and to induce them to institute experiments to test the comparative efficiency of his engine and that of Savery.[2] Many changes, however, had occurred during his long absence on the Continent. Boyle and Hook, who had befriended him in his earlier years, were both dead. A patent for the fire engine was held by Savery. Need it be wondered at that his solicitations led to no result!

Papin lingered in England for several years, living on small payments which he received from the Royal Society for services rendered. In 1712 he finally quitted England. The last notice of him is in 1714.[3] The end of his career is shrouded in obscurity; the place and time of his death being alike unknown.

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[1] *Vie de Papin*, par L. de la Saussaye et A. Pean, Vol. I., p. 238.

[2] *A History of the Royal Society*, by C. R. Weld, London, 1848, Vol. I., pp. 380-2. *Vie de Papin*, par L. de la Saussaye et A. Pean, Vol. I., pp. 240-1. What form of engine Papin proposed to employ seems uncertain. Was it the atmospheric engine of 1690 or the steam-fountain engine of 1707? As he speaks of discharging bullets and of propelling vessels with his engine, it is difficult to imagine how it could be the latter. On the other hand his engine of 1690 was described by him as suited to perform both of these operations.

[3] *Vie de Papin*, par L. de la Saussaye et A. Pean, Vol. I., p. 254.

CHAPTER VII.

NEWCOMEN'S ATMOSPHERIC ENGINE BROUGHT FORWARD AS AN IMPROVEMENT OF SAVERY'S FIRE ENGINE.

FROM these records of unavailing efforts on the part of Savery and Papin to introduce their respective fire engines into public favour, we now turn to follow the history of Newcomen's invention, which was immeasurably superior to any engine that had preceded it

Whether the return of Papin to England had any influence in inducing Newcomen to resume his experiments with the atmospheric engine, or whether he was brought back to his former project solely by the failure of Savery's engine, we cannot tell. It is highly probable that Newcomen was aware of Papin's return to London, but it is very improbable that Papin knew anything whatever regarding Newcomen's experiments.[1]

[1] *Vie de Papin*, par L. de la Saussaye et A. Pean, Vol. I., p. 167. Desaguliers states that Newcomen's experiments were made in private. [*Experimental Philosophy*, Vol. II., p. 532.]

The final departure of Papin from England appears to have been nearly contemporaneous with, if not anterior to, the building of Newcomen's first engine.

How Newcomen was occupied during the period preceding the appearance of his engine, contemporary writers do not inform us. Later writers, it is true, have attempted in some measure to fill up the void in his history, but their statements can be shown to be quite without foundation. We are told that Newcomen was about to take out a patent for his invention; that Savery, hearing of it, insisted upon having an interest in it; and that a patent was accordingly taken out in the year 1705, in the joint names of Newcomen, Cawley, and Savery. We are even furnished with figures of Newcomen's patent engine as it was in 1705. Now that all this is wholly erroneous, we have several independent proofs. In the first place, Switzer distinctly states that Savery having obtained his patent before Newcomen knew of it, Newcomen was glad to come in as a partner to it;[1] secondly, there is no such patent as the one alleged to have been taken out in 1705;[2] thirdly, a deed, still in existence, shows that Newcomen's engine was brought out under Savery's patent, and that the patent for it ceased in the year 1733, or precisely at the end of the

[1] *Hydrostaticks and Hydraulicks*, Vol. II., p. 342.

[2] See *A Treatise on the Cornish Pumping Engine*, by William Pole, F.R.A.S., F.G.S., London, 1844, p. 10. This fact can also easily be verified by a reference to the published lists of patents.

term of thirty-five years granted to Savery;[1] fourthly, contemporary writers assign the invention of Newcomen's engine to a date several years later than 1705.

Dr. Desaguliers is the only writer of the period who attempts to give a detailed account of the early history of Newcomen's invention. In the second volume of his *Course of Experimental Philosophy*, which was ordered by the Royal Society to be printed in 1743, and was published in the following year (1744), after describing Savery's failure with the York-buildings engine, he continues: "These discouragements stopped the progress and improvement of this engine, till Mr. Newcomen, an ironmonger, and John Cawley, a glazier, living at Dartmouth, brought it to the present form in which it is now used, and has been near these thirty years."[2] In the notes appended to the same volume, Dr. Desaguliers enters into the question of the date of Newcomen's invention with greater detail. His account there is as follows:—

"About the year 1710, Tho. Newcomen, ironmonger, and John Calley, glazier, of Dartmouth, in the county of Southampton, (Anabaptists), made then several experiments in private, and having brought it to work with a piston, &c., in the latter end of the year 1711, made proposals to draw the water at Griff, in Warwickshire; but their invention meeting not with reception, in March following, through the acquaintance of Mr. Potter of Bromsgrove, in Worcestershire, they bargained to draw water for Mr. Back of Wolverhampton, where, after a great many

[1] See *post*, p. 112.

[2] *Experimental Philosophy*, Vol. II, p. 467.

laborious attempts, they did make the engine work; but not being either philosophers to understand the reasons, or mathematicians enough to calculate the powers, and to proportion the parts, very luckily by accident found what they sought for. They were at a loss about the pumps, but being so near Birmingham, and having the assistance of so many admirable and ingenious workmen, they soon came to the method of making the pump-valves, clacks, and buckets (1712); whereas they had but an imperfect notion of them before."[1]

Desaguliers, it must be remembered, was to some extent a rival of the patentees of the fire engine.[2] He invented, or contrived, a few trifles himself. He may have felt the patent for the fire engine somewhat galling to his inventive propensities.[3] But be this as it may, he is universally considered not to have done justice to the merit of the inventors. He charges Savery with borrowing his ideas from the Marquis of Worcester without acknowledgment, and with having burnt all the copies of the Marquis's book he could find in order to conceal the fact:[4] now he attributes the invention of Newcomen and Cawley to a lucky

[1] *Experimental Philosophy*, Vol. II., pp. 532, 533.

[2] "Desaguliers," says Mr. Muirhead, "would fain have had the credit of improving it beyond all the devices imagined by Lord Worcester, Savery, Newcomen, Cawley, and any others who might have had a hand in the great machine." [*Life of Watt*, 2nd ed., p. 153.]

[3] In the year 1717, or 1718, Desaguliers built one of Savery's engines for Peter the First for his garden at St. Petersburg. This was immediately after the death of Savery. Desaguliers subsequently built other six engines on the same construction. [*Experimental Philosophy*, Vol. II., p. 488.]

[4] *Ibid.* pp. 465-6.

accident.[1] He evidently did not know that the project of constructing an atmospheric engine had occupied the attention of Newcomen many years previous to this date; that he had corresponded with Dr. Hook on the subject, and was much better acquainted with scientific facts than he supposed. His charge against Savery has been discredited; some of his statements regarding Newcomen's invention ought, we think, to share the same fate. That the first atmospheric engine, however, was built near Wolverhampton, is corroborated by Dr. Wilkes, who, speaking of Newcomen, says that he "fixed the first [engine] that ever raised any quantity of water at Wolverhampton, on the left-hand side of the road leading from Walsall to the town, over against the half-mile-stone."[2]

[1] Desaguliers exhibits a great anxiety to impress upon his readers that the invention of the atmospheric engine was wholly accidental—that this powerful, ingenious, and complicated machine was begotten by a "Chapter of Accidents," and that its inventors were entitled to no credit. "If the reader," he says "is not acquainted with the history of the several improvements of the fire-engine since Mr. Newcomen and Mr. Cawley first made it go with a piston, he will imagine that it must be owing to great sagacity, and a thorough knowledge of philosophy, that such proper remedies for the inconveniencies and difficult cases mentioned were thought of. But here has been no such thing; almost every improvement has been owing to chance!" [*Experimental Philosophy*, Vol. II. p. 474]. Had we known as little about James Watt as we do about Newcomen, we should doubtless have had his inventions explained away after a similar fashion. "It has long been the hard fate of most inventors," says Muirhead, "if their inventions are of any real value, to be assailed by . . . . rivals." [*Life of Watt*, 2nd ed., p. 388.]

[2] Shaw's *History of Staffordshire*, Vol. II., P. I., p. 120.

Notwithstanding the hostility of Desaguliers towards the inventors of the atmospheric engine, it can be ascertained from a careful examination of his remarks, that the machine was much more perfect when brought into public notice than has generally been supposed It is clear that this first engine was an automatic, or *self-acting*, machine.[1]

It would appear that at the time of the erection of this engine, condensing by injection had not yet been invented. The steam was condensed from the outside, but whether by merely allowing the cylinder to cool after the manner of Papin, or by the application of cold water after Savery's method, we are not informed.[2] The superior method of condensing by injection, according to Desaguliers, was discovered by accident. " One thing," he says, " is very remarkable: As they at first were working they were surprised to see the engine go several strokes, and very quick together, when after a search they found a hole in the piston, which let the cold water[3] in to condense the steam in

[1] The usual statement that the cocks were at first turned by boys may either have arisen from a confusion between Savery's fire engine and Newcomen's, or from the fact that Newcomen employed a "buoy," floating upon the surface of the water in the boiler, to open the injection-cock in the earliest form of the self-acting mechanism.

[2] It has been stated by some writers that Newcomen employed two cylinders—an outer and an inner one—and that he effected the condensation of the steam by pouring cold water between them. So far as the writer is aware there is no reliable authority for this statement. It is commonly accompanied by some other palpable errors with which it appears to be connected.

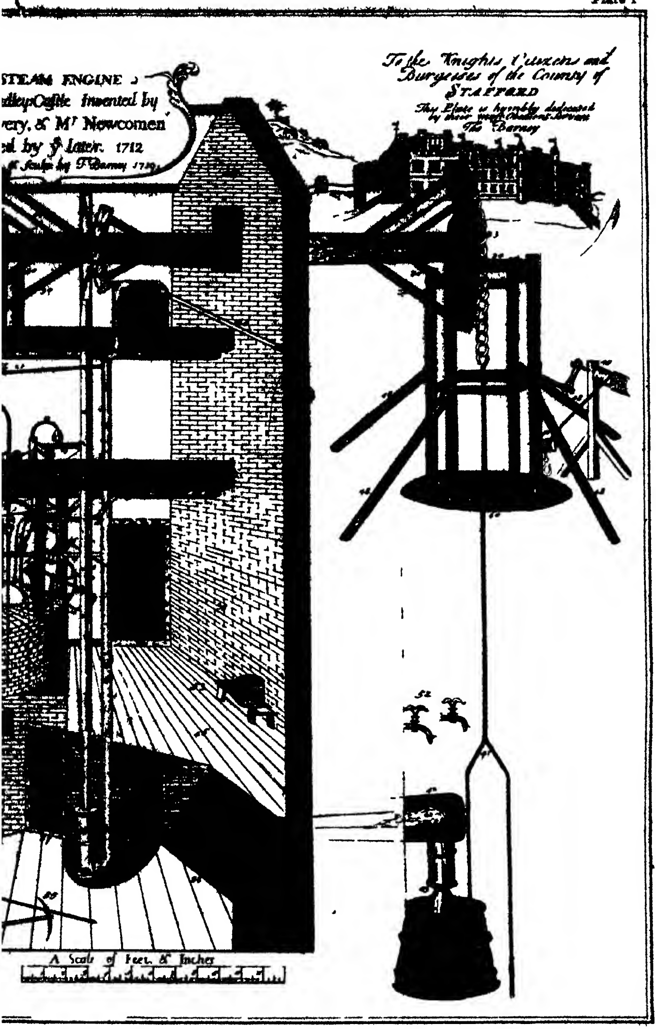
[3] *i.e.* The water lying on the piston.

the inside of the cylinder, whereas before they had had always done it on the outside."[1]

An engraving[2] is still in existence of an atmospheric engine built by Newcomen in 1712, and designated "The Steam Engine near Dudley Castle." The exact correspondence in point of date, coupled with the fact of Dudley Castle being in close proximity to Wolverhampton, renders it almost beyond doubt that the engraving represents the engine referred to by Dr. Desaguliers and Dr. Wilkes, or, in other words, Newcomen's first engine. This interesting relic, of which Plate I. is a reduced facsimile, gives us some idea of the wonderful achievements of Newcomen and his

[1] *Experimental Philosophy*, Vol. II., p. 533. According to the same writer the way of "leathering the piston" was also discovered by accident, about 1713. "Having then screwed a large broad piece of leather to the piston, which turned up the sides of the cylinder two or three inches; in working it wore through, and cut that piece from the other, which, falling flat on the piston, wrought with its edge to the cylinder, and having been in a long time was worn very narrow; which being taken out, they had the happy discovery, whereby they found that a bridle rein, or even a soft piece of rope or match going round would make the piston air and water-tight." *Ibid.*

[2] Two copies of the engraving are known to exist, one being in the "William Salt Library" at Stafford, and the other in the possession of Mr. Samuel Timmins, F.S.A., Birmingham. The accompanying illustration represents the latter copy, Mr. Timmins having very kindly allowed his engraving to be photographed for the purpose. This interesting print appears to have been first brought to light in connection with the exhibition of scientific apparatus at the South Kensington Museum in 1876. [See Catalogue of the Special Loan Collection, &c., 3rd ed., London, 1877, p. 451; see also the *Engineer*, May 26th, 1876, and November 28th, 1879, in the latter of which a figure of the print is published.]


STEAM ENGINE
dley Castle Invented by
very, & Mr Newcomen
ed by ye Later. 1712
T. Barney
To the Knights Citizens and Burgesses of the County of STAFFORD
This Plate is humbly dedicated by their ... Servant
Tho Barney
A Scale of Feet & Inches

associate Cawley, and of the mature form which they had given to the machine at this early period. Contrasting the atmospheric engine as here exhibited, with the simple mechanism of Papin, we cannot fail to be astonished at the prodigious advance which had been effected. We recognise the principle propounded by Papin, but how wonderfully improved is the machine! The subject of the atmospheric pressure, however, no longer was regarded with the interest previously attached to it. The atmospheric engine, admirable as it was, excited little attention from the scientific world.

We cannot tell whether Newcomen took the idea of producing a vacuum by the condensation of steam from Savery or from Papin, but as his engine was doubtless directly derived from the cylinder and piston apparatus of the latter, it is probable that this method of producing a vacuum under the piston was also taken from him. On the other hand the employment of a separate boiler for generating the steam was suggested, we may be sure, by the construction of Savery's engine.

The cylinder, both as regards its design and material, was nothing but a monster air-pump barrel. In all the earlier engines it was made of *brass.* The piston consisted of a circular brass disc, on the upper side of which a leather flap was secured, which was kept soft

and air-tight by means of a stratum of water, a few inches in depth, constantly lying upon it.

The early boilers, like those employed by Savery, appear to have been made of copper.[1]

The engine was applied to actuate a common lifting-pump, a wooden beam, or lever,—a gigantic *pump-handle*, in fact—being used to communicate the pull of the piston to the pump-rods; the weight of the pump-rods in turn brought back the piston to the top of the cylinder, on the admission of steam below placing it in equilibrium.

The use of fresh steam at every stroke of the engine, and the introduction of condensing water into the inside of the cylinder, gave rise to two inconveniences which had to be provided against. In the first place some means had to be arranged for drawing off the condensing water, together with the water resulting from the condensation of the steam. This was effected by the application of a pipe called the sinking or *eduction-pipe*, which, issuing from the bottom of the cylinder, was carried down a few feet to enable the water to run out by its own gravity, on the re-admission of steam into the cylinder.[2]

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[1] The top of the boiler was afterwards very commonly made of lead. [*Experimental Philosophy*, Vol. II., p. 472.] Wrought-iron plates subsequently came into use, first to form the bottom of the boiler, and afterwards the whole of it.

[2] The eduction pipe was usually only a few feet in length. Its mouth terminated in a cistern, being turned upwards and provided with a valve, which allowed the water to escape, but prevented its return on the vacuum being formed inside the cylinder. Mr. Stuart

In the second place, a certain portion of air, freed from the condensing water, remained in the cylinder. This air, if allowed to accumulate, tended to give rise to what was termed *wind-logging*, which would in the course of time have altogether interfered with the production of a vacuum under the piston, and consequently with the working of the engine. To prevent the accumulation of this air, a valve named the *snifting-valve* (from the noise which it made) was applied, which, opening upwards, and sitting in a little cup filled with water, admitted of air being blown out, while at the same time it prevented the entrance of the external air on the vacuum being produced in the interior of the cylinder.

Of all the ingenious contrivances invented by Newcomen and his associate, the *self-acting gear* was perhaps the most remarkable.[1] By means of this

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states that the eduction pipe was carried to a depth of about thirty feet. [*Anecdotes of Steam Engines*, Vol. I., p. 153.] This, however, is clearly a mistake. Desaguliers speaks of four feet as sufficient. [*Experimental Philosophy*, Vol. II., p. 473.]

[1] With the drawing of the engine, built near Dudley Castle in 1712, before us, we cannot do otherwise than regard Dr. Desaguliers' story with reference to the boy Potter, as in all probability apocryphal. It was not published until fully thirty years after the date of the event which it records. His statement is as follows:—"They used before (1713) to work with a buoy in the cylinder, inclosed in a pipe, which buoy rose when the steam was strong, and opened the injection and made a stroke; thereby they were capable of only giving six, eight, or ten strokes in a minute, till a boy, Humphry Potter, who attended the engine, added (what he called *scoggan*) a catch that the beam Q [*i.e.* the sliding-beam or plug-rod, *not the lever*] always opened:

ingenious mechanism the engine was made to work entirely of itself. It was as it were provided with hands, by which it opened and closed the steam-valve and injection-cock at the proper moment. On the piston arriving at the top of its stroke, the *regulator* or steam-valve required to be closed, and the *injection-cock* to be opened immediately afterwards. A vacuum was then formed by the condensation of the steam, and the piston was driven down to the bottom of the cylinder by the pressure of the atmosphere. As the piston arrived near the end of the down-stroke, the injection-cock required to be closed and the regulator to be opened immediately afterwards, whereupon steam being admitted into the cylinder the piston was placed in equilibrium, and the weight of the pump-rods in the pit brought it again to the top of the cylinder.

The apparatus by which the injection-cock was opened and closed was named from its shape the F; and for a similar reason that which opened and closed the regulator was called the Y. In the earliest form of the self-acting gear, the steam in the boiler regulated

and then it would go fifteen or sixteen strokes in a minute. But this being perplexed with catches and strings, Mr. Henry Beighton, in an engine he had built at Newcastle-on-Tyne in 1718, took them all away, the beam itself simply supplying all much better." [*Experimental Philosophy*, Vol. II., p. 533.] In the engraving we have "Scoggen and his mate, who work double to the boy," apparently forming an integral part of the earliest or buoy-arrangement of self-acting gear, in 1712. The story was doubtless invented by the detractors of the patentees.

the number of strokes made by the engine, in the following manner:—A tube, called the *buoy-pipe*, passing through the top of the boiler, was led down about a foot below the surface of the water. Within this tube was a cylindrical float, or buoy, reposing upon the surface of the water, and from the buoy a rod was carried upwards and connected with a catch made to receive the end of the F so as to keep the injection-cock closed. We will suppose the piston to be at the top of the cylinder which is full of steam. The regulator has been closed by its own mechanism, and the engine is ready for its down-stroke. The steam in the boiler, having no outlet, drives up the water in the buoy-pipe and raises the buoy, which in turn, by means of the rod and connections already mentioned, disengages the injecting-hammer, or F, from the catch which held it, and the weight at the end of it, in falling, throws open the injection-cock and starts the piston downwards. On the piston arriving near the bottom of the cylinder, a pin in the *sliding-beam*, or plug-rod, brings back the F again into the catch, thereby closing the injection-cock; and immediately afterwards another pin on the plug-rod, striking against one of the arms of the Y, throws open the regulator and admits the steam into the cylinder, whereupon the pressure in the boiler being relieved the buoy returns to its first position. On the piston reaching the top of the cylinder another pin in the plug-rod, coming into contact with the other arm of

the Y, closes the regulator, and the cylinder remains ready for the buoy again giving the injection. The play of the F and the Y was confined within certain limits by means of straps attached to them.

The buoy apparatus continued to be used in some engines for many years.

The engine near Dudley Castle is stated to have made twelve strokes a minute, and to have raised ten gallons per stroke from a depth of fifty yards. The pumps were in two lifts of twenty-five yards each.

The arrangements for supplying the injection-water, for running water on to the top of the piston, and for feeding the boiler therefrom, are shown with sufficient clearness in the plate.

CHAPTER VIII.

THE ATMOSPHERIC ENGINE IS AT ONCE ADOPTED FOR DRAINING COAL MINES, AND RENDERS GREAT ASSISTANCE TO THE MINING COMMUNITY.

NEWCOMEN'S engine was introduced to the public as an improvement of Savery's engine, and, as already stated, under his patent. This arrangement was doubtless a good one for protecting the invention, without the necessity of obtaining another patent for it, but several anomalies are directly traceable to this circumstance. The atmospheric engine, so different in its construction and principle from Savery's machine, took the name of *Fire engine*[1] from it. It was regarded by

[1] It is remarkable that the engine near Dudley Castle is termed a *steam engine* in the engraving above mentioned. It is the only instance known to the writer in which this name was applied to the machine in the early part of its history. The copy in the "William Salt Library" at Stafford has at the bottom of the print—Birmingham: Printed and Sold by H. Butler in New Street. No date is attached, the engraver's date (1719), being probably regarded as sufficient. A curious evidence of the authenticity of this date has been elicited by inquiries instituted by Mr. Timmins, from which it appears that the first Birmingham book was published in the year 1719, and came from

the public as the joint invention of Savery and Newcomen, though we do not hear that Savery ever rendered any active assistance either in its invention, or in the erection of engines. Newcomen's engine is by some writers called Savery's,[1] as there is reason to believe that Savery's engine has sometimes been taken for Newcomen's. On Savery again has been bestowed much praise as the inventor of the cylinder and piston engine, which properly ought to have been conferred upon Newcomen and his associate. These things naturally resulted from the way in which the atmospheric engine was first brought into public notice.

Newcomen's engine combined power and safety in a remarkable degree. "The utmost damage that can come to it," says Switzer, "is its standing still for want of fire."[2] It is little to be wondered at that he speaks in terms of admiration of the inventor and his engine. "This ingenious gentleman [Mr. Newcomen]," he says, "to whom we owe this late invention, has with a great deal of modesty, but as much judgment, given the finishing stroke

the same press; the inscription upon it being—Birmingham: Printed by H. B. in New Street.

[1] *e.g.* Belidor, Bossut, Dr. Dalton, Dr. Erasmus Darwin, &c.

[2] *Hydrostaticks and Hydraulicks*, Vol. II., p. 342. While Savery sometimes used steam of a pressure 150 lbs. on the square inch above the atmosphere, the steam employed in Newcomen's engine was "but a little stronger than air." Desaguliers describes it as "in a fluctuating condition, sometimes stronger and sometimes weaker than common air; but never $\frac{1}{10}$th stronger nor $\frac{1}{10}$th weaker." [*Experimental Philosophy*, Vol. II., p. 472.]

to it.[1] It is, indeed, generally said to be an improvement to Mr. Savery's engine; but I am well informed that Mr. Newcomen was as early in his invention as Mr. Savery was in his."[2] "This last improvement of it," he says in another place, "by Mr. Thomas Newcomen, makes it undoubtedly the beautifullest and most useful engine that any age or country ever yet produced."[3]

The miners, who had declined to avail themselves of Savery's engine, quickly appreciated the advantages of Newcomen's invention. The number of engines was rapidly augmented, and a few years saw them in use for draining mines, in all parts of the kingdom. The following are a few notices regarding some of the earliest engines:—

A fire engine, which had been erected at some waterworks in London, was purchased by Sir James Lowther, of Whitehaven, in Cumberland. It was sent by ship from London to Whitehaven, where it was erected at a coal-pit in the "Gins," afterwards known as the "Gins fire engine pit." It was said to have been the second fire engine erected in England.[4] Bradley mentions this engine, and from the terms in which he refers to it,

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[1] *i.e.* The fire engine.

[2] *Hydrostaticks and Hydraulicks*, Vol. II. p. 341. [3] *Ib.* p. 335.

[4] Hutchinson's *History of the County of Cumberland*, Carlisle 1794, Vol. II., p. 60. See also a paper on the Archæology of the West Cumberland Coal-trade in the *Transactions of the Cumberland and Westmoreland, Antiquarian and Archæological Society*, Part II., Vol. III., for 1877-8, where it was stated that the pit at which the engine was built was twenty-one fathoms deep.

it was evidently one of Newcomen's engines. Writing in 1718, after treating of Savery's engine and the Persian wheel, he observes as follows: "As for other inventions for the same purpose of raising water, I shall refer my readers to the engines themselves .... but above all others that I have yet heard of for ingenious contrivance, the engine belonging to — Louder, Esq., of Whitehaven, which I am told is a considerable improvement upon Mr. Savory's invention."[1]

"The first steam engine in Cornwall," Mr. Carne informs us, "was erected on Huel Vor, a tin mine in

[1] *New Improvements of Planting and Gardening*, by Richard Bradley, F.R.S. The third part, 2nd ed., London, 1718, p. 180. If further evidence were required to prove the fact of this engine at Whitehaven being one of Newcomen's, it is supplied by Dr. Stukeley, who visited the Whitehaven collieries in the course of his northern tour made in the year 1725. The following is the account of the engine which he gives: "At last the famous fire-engine discharges the water, which is a notable piece of machinery working itself entirely: it creates a *vacuum* by first rarefying the air with hot steam, then condenses it suddenly by cold water; whence a piston is drawn up and down alternately, at one end of the beam: this actuates a pump at the other end, which, let down into the works, draws the water out: it makes about fourteen strokes a minute, so that it empties 140 hogsheads in an hour with moderate working." [*Itinerarium Curiosum*, by William Stukeley, M.D., &c., 2nd ed., London, 1776; *Iter Boreale*, p. 52.] At the date of Dr. Stukeley's visit, the Whitehaven mines had attained a depth of fifty fathoms, but with the aid of atmospheric engines, and under the able management of Carlisle Spedding, much deeper sinkings were shortly afterwards effected. Spedding is stated to have been sent to Newcastle by Sir James Lowther, in order to learn the system of working pursued in the mines there, and to have accomplished this by obtaining employment as a coal-hewer, under a fictitious name, being popularly known as "Dan."

Breage, which was at work from 1710 to 1714. Whether this was Savary's or Newcomen's is doubtful, as Newcomen's engine does not appear to have been much known before 1712."[1] Professor Pole was of opinion that this was probably one of Newcomen's first attempts,[2] but in the absence of further evidence this must remain uncertain.

"The first steam engine in the North" [*i.e.* the Newcastle-on-Tyne district], according to Brand, 'is said to have been built upon a moor called Washington Fell, about nine miles south-east of Newcastle-on-Tyne, for a colliery upon the river Were [Oxclose Colliery]. I have seen," he says, "the remains of the shell of this building.

"The next, as I was informed by a very old man concerned in coal-mines, was at Norwood, near Ravensworth Castle, in the same neighbourhood.

"About the year 1713 or 1714, the first fire engine on the north side of the river Tyne is said to have been erected at Biker Colliery, the property of Richard Ridley, Esq. The engineer was the reputed son of a Swedish nobleman, who taught mathematics at Newcastle."[3]

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[1] *On the period of the commencement of Copper Mining in Cornwall; and on the Improvements which have been made in Mining*, by Joseph Carne, Esq., F.R.S.; in the *Transactions of the Royal Geological Society of Cornwall*, Vol. III.

[2] Pole on the *Cornish Pumping Engine*, p. 12.

[3] *The History and Antiquities of the Town, and County of the Town, of Newcastle-upon-Tyne*, by John Brand, M.A., London, 1789,

No particulars appear to be preserved regarding the above engines, but we have some information in reference to one built in Yorkshire about the same date. "Mr. Smeaton," says Farey, "made many inquiries into the particulars of a fire-engine, which was erected about the year 1714, by the patentees, at a mine on the Moor Hall estate, at Austhorpe, in Yorkshire, where Mr. S. resided. . . . Mr. Calley attended the building of it, and died at Austhorpe in 1717. The patentees had 250*l.* a year, for working and keeping the engine in order; but they burned out four boilers in the time it was worked, which was only about four years. An old man who had worked the engine in his youth, told Mr. S. that the cylinder was twenty-three inches

Vol. II. p. 686. Who this Swedish engineer was we are not informed. Can it have been Triewald? The following account of Triewald is given in Stuart's *Historical and Descriptive Anecdotes of Steam Engines*, Vol. II., p. 618. "Sir Martin Triewald was a Swede, who came to England in 1716 to obtain information regarding the mode of mining followed at Newcastle. He remained in that neighbourhood for some years, and was employed as an engineer at a coal-mine; he was a pupil of Desaguliers, and some of his improvements on the diving-bell are described in the Doctor's *Experimental Philosophy*. He returned to Sweden in 1726, and erected an atmospheric engine, the parts of which he got fabricated in England. He was captain of mechanics, and military architect to the King of Sweden; and was in correspondence with some of his friends in the Royal Society until his death. He invented a mode of warming conservatories by hot water." See also *Farey on the Steam Engine*, p. 212, note. On the 29th of July, 1722, a patent for an atmospheric engine of some kind was granted to Martin Triewald, of Newcastle-on-Tyne. *Vide*, No. 449.

diameter and six feet stroke, and it would make about fifteen strokes per minute when worked by hand, but in general it made about twelve when working itself. The pit was forty-seven yards deep, and the pumps, which were in two lifts and nine inches bore, drew the water up thirty-seven yards, into a level, which conveyed it away. The pump which supplied the cold water for injection, was about four inches diameter and three feet stroke. The boiler bottom was set two feet eight inches above the fire-grate; it burned twenty-four or twenty-five corves of coals in twenty-four hours."[1]

For a year or two after the date of the erection of the engine at Austhorpe, we have no notices of the building of any engines. During this time Newcomen lost his two partners; Savery dying in 1715 or 1716, and Cawley (or Calley), as we have seen, in 1717.

We next find Henry Beighton, a skilful engineer, interesting himself in the atmospheric engine, examining

[1] *A Treatise on the Steam Engine*, by John Farey. London, 1827, p. 155, note. "Smeaton," says Farey, "was informed that when this engine [at Austhorpe] was built, there were only three engines in existence. The first which was made, was near Coventry, and had no working gear, but the cocks were opened and shut by hand; there were two others at Newcastle, and the Austhorpe engine was supposed to be the fourth engine which Newcomen made." As the engine at Wolverhampton (said to have been the first of Newcomen's engines), and the engine bought at London by Sir James Lowther (said to have been the second made), are both omitted in the above account, it is obvious that the information supplied to Smeaton was defective. Regarding the engine near Coventry, see *ante*, p. 66 and *note*.

its performances in a scientific manner, constructing a table of the dimensions of engines for raising water from given depths, and modifying some of the arrangements of the machine itself. Beighton was a native of Warwickshire, and resided at Griff, near Coventry. He was eminently skilled in machinery, and followed the profession of a civil engineer, being the most distinguished of his time. He was an intimate friend of Dr. Desaguliers, to whom he communicated much valuable information touching mechanics, engines, &c.[1] In the year 1711 Beighton projected a new map of Warwickshire, but not meeting with sufficient encouragement at the time, it was not commenced till 1722.[2] In 1713 he became editor of the *Ladies' Diary*, which he conducted for the Stationers' Company during a period of thirty years, with great satisfaction to the company.

Desaguliers informs us that about the year 1717 he communicated to Mr. H. Beighton the use of the *steel-yard* over the puppet-clack, or safety-valve, which he applied to some engines.[3] In the same year Beighton published his table showing the powers of engines of given sizes, which, being the earliest table of the kind, and of interest on this account, is reproduced on

[1] *The Philosophical Transanctions*, abridged by Drs. Hutton, Shaw, and Pearson, Vol. VII., p. 442, note. *Experimental Philosophy*. Vol. II, p. 481. [2] See *Ladies' Diary* for the years 1722 and 1728.

[3] *Experimental Philosophy*. Vol. II., p. 533.

A calculation of the power of the Fire Engine, showing the diameter of the cylinder (or steam-barrel), and bore of the pump, that is capable of raising any quantity of water, from 48 to 440 hogsheads an hour, at any depth from 15 to 100 yards

Diameter of bore	Will hold in a yard	Will draw by a six feet stroke	Weighs in one yard	At sixteen strokes a minute.	Sixty three gallons to a hogshead	In one hour	Diameter of the cylinder in inches — The depth to be drawn in yards.												
Inchs	Galls	Galls	Lbs Aver	Galls	Hog Galls	Hog Galls	15	20	25	30	35	40	45	50	60	70	80	90	100
12	14 4	28 8	146	462	7 21	440	16½	21¾	24	2[illegible]½	28½	30½	32½	34½	37½	40			
11	12 13	24	123 5	335	6 20	369 33	17	19¾	22	21¾	26¼	28	29¾	31½	34½	37	39½		
10	10·02	20 04	102	320	5 5	304 48	15½	18	20	22	23¾	25¼	27	28¼	31½	33¾	36	38½	40
9	8 12	16 2	82 7	259 8	4 7	247 7	14	16¼	18	20	21½	23	24½	25	28	30½	33	35	36½
8½	7 26	14 5	73 9	232 3	3 43	221 15	13½	15¼	17¼	19	20½	21¾	23	24	26½	28½	31	32½	35½
8	6 41	12 8	65 3	205 2	3 16	195 22	12½	14½	16½	18½	19	20½	21½	23	25	27	29	30½	32½
7¾	6 01	12 2	61 2	192 3	3 2	182 13	12	14	15½	17½	18¾	19¾	21	22	24½	26	28	29½	31½
7½	5 66	11 3	57 6	181 1	2 55	172 30	11	13¾	15	16½	18	19	20	21½	23½	25	27	28½	30½
7	4 91	9 8	50 0	157 1	2 31	149 40	10¾	13	14	15½	16¾	18¾	19	20½	22	24	25½	27	28½
6½	4 23	8 4	43 0	135 3	2 9	128 54	10	12	13	14	15½	16¼	18	19	20	22	23	24½	26½
6	3 61	7 2	36 7	115 5	1 52	110 1	9½	11	12	13	14	15½	16	17	19	20½	22	23	24½
5½	3 13	6 2	31 8	99 2	1 36	94 39		10	11	12	13	14	15	15¾	17	19	20	21	22½
5	2 51	5 0	25 5	80 3	1 7	66 61			10	11	11¾	13	13¾	14	15½	16¾	18½	19½	20½
4½	2 02	2 4	20 5	64 6	1 1	60 60				10	11	11¾	12	13½	14	15	16	17	18½
4	1 6	3 2	16 2	51 2	0 51	48 51					9	10	11	11½	12	13½	14	15	16

The table is formed on this foundation viz —The ale gallon (containing 282 cubic inches) filled with pure running water weighs 10 lb 3 oz averdupoids and a superficial inch on a vacuum takes in about 14 lb 13 oz of the atmosphere, when the mercury stands at a medium in the barometer

But allowing for several frictions and to give a considerable velocity to the engine experience has taught us to allow but little more than 8 lb to an inch in the cylinders bas that it may make about sixteen strokes in a minute at about six feet to each stroke

This calculation is but the ordinary power in practice for with large boilers it will go currently twenty or twenty five strokes per minute and each of them seven or eight feet and then a pump of nine inches bore will discharge more than 320 hogsheads per hour and for other sizes proportionably

An Example of the Use of the Table —Suppose it were required to draw 150 hogsheads per hour at ninety yards deep in the seventh column I find the nearest number 149 hogsheads and against it in the first column I find a seven inch bore then under 90 the depth on the right hand in the same line, I have twenty seven inches the diameter of the cylinder fit for that purpose—and so for any other

Hen Beighton 1717

the preceding page. It is worthy of remark that the largest diameter of cylinder which he gives is forty inches; the greatest depth 100 yards; as also that with large boilers the engine could already be made to go currently twenty or twenty-five strokes per minute.[1]

Desaguliers credits Beighton with having applied a simple form of self-acting gear to an engine he built at Newcastle-on-Tyne in the following year [1718],[2] but without either describing the form of his apparatus, or of that which he states it to have superseded. Several forms of self-acting mechanism are met with in drawings of engines, a few years after this date. Some of these exhibit a buoy as still in use, while others are without it, the F as well as the Y being worked entirely by the sliding-beam or plug-rod.

The great sphere for atmospheric engines lay in the coal-fields, where a supply of fuel could be easily and

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[1] The table was afterwards published by Beighton in the *Ladies' Diary* for the year 1721, p. 22. He calls it "A Physico-Mechanical Calculation of the power of an engine." In introducing the matter he remarks that "it were much to be wished that they who write on the mechanical part of the subject [*i.e.* engines of various kinds] would make themselves masters of the philosophical and mechanical laws of (motion or) nature; without which it is morally impossible to proportion them so as to perform the desired end of such engines. The following table I calculated in 1717, for a particular sort of engine, wrought by the pressure of the atmosphere, on the vacuum of an exhausted receiver, which is easily done sixteen or twenty times a minute."

[2] *Experimental Philosophy*, Vol. II., p. 533. The *Ladies' Diary*, usually dated from Coventry or Griff, for the year 1719 is dated from "Aula Fellonia in Com. Dunelm., 11 Idiis Julii, 1718."

cheaply procured. It was now possible to open out and work collieries by the help of these engines, which could not be worked before.

The engine was introduced into collieries in Scotland within a few years after its invention. At what precise date or in what place the first was built, we are not informed. At the beginning of the present century, Mr. Robert Bald, an eminent Scotch engineer, made every inquiry to ascertain this, but without success.[1] There are two engines, however, both of which are claimed as having been the second built. Of these, one was erected at a colliery near Saltcoats, in Ayrshire, in the year 1719. The cylinder was brought from London, and was eighteen inches in diameter.[2] The other was applied at Elphingstone Colliery, in the parish of Airth, in Stirlingshire, the date of its erection not being recorded.[3] Mr. Bald supposed it to have been about 1720.[4]

Regarding the invention of the steam engine, the above-mentioned writer remarks that it "produced a new æra in the mining and commercial interests of Britain, and as it were in an instant put every coal-field, which was considered as lost, within the grasp of its owner."[5]

[1] *A General View of the Coal Trade of Scotland*, &c., by Robert Bald, Edinburgh, 1808, p. 18.

[2] *The Statistical Account of Scotland*, ed. by Sir John Sinclair, Bart., Edinburgh, 1793, Vol. VII., p. 11.

[3] *Ibid.* Vol. III., p. 489.

[4] *View of the Coal Trade of Scotland*, p. 20.

[5] *Ibid.* p. 24.

The following evidence, taken at Newcastle-on-Tyne in 1722, illustrates the benefit that was being experienced by the mining population from the substitution of the atmospheric engine for horse labour :—

"John Barnes's affidavit, sworn December 21, 1722, respecting calculations of the expense of winning Walker Colliery, before it became the property of the corporation [of Newcastle-on-Tyne], A.D. 1716, 'which came to 5,011*l.* 18*s.* and the charge of water was therein calculated as if to be drawn by horses, whereas now it may be done much cheaper by help of a fire engine'—Sir Robert Raymond's Report.

"By the above," says Brand, "it appears that Hugh Bethell, Esq., then owner (A.D. 1711) of Walker Manor, attempted to sink two pits nigh the windmill there, and adjoining to the Shields road; that with great difficulty and the help of two horse-gins, both going night and day, to draw water, they sunk about thirty fathoms. *Ibid.*—The working now by fire engines is much cheaper than formerly.

"Affidavit of William Cotesworth, Esq., 1722, January the 3rd, *ibid.*—Elswick Colliery was attempted to be won about forty years ago.—The undertakers failed.—The said Elswick Colliery had a few years ago been won, and, by the help of fire engines, was then a working colliery." [1]

Though the first offer of the inventors of the atmospheric engine to draw the water at Griff, near Coventry, in the year 1711, was declined, we find several engines now at work in the neighbourhood. Mr. Beighton's map, made from actual survey in the year 1725, exhibits fire engines at three collieries in Warwickshire.

[1] Brand's *History of Newcastle-upon-Tyne*, Vol. II., pp. 685-6, note.

Of these, one was at Griff, and the two others at collieries between Griff and Coventry.

Desaguliers gives drawings and a description of an engine at Griff, as it worked about 1723.[1] This engine is shown in Fig. 20. The cylinder, which was of brass, was twenty-two inches in diameter, and eight or nine feet long. Several modifications are observable in the mechanism of the engine. The sliding-beam, or plug-rod, is no longer used for raising water, but devoted entirely to the working of the self-acting gear. This gear itself is of an extremely simple type (Fig. 21); the buoy arrangement is dispensed with; the F and the Y are so much altered in form as to be unrecognisable by their names.[2] The method of opening and closing the injection-cock by means of toothed quadrants was, however, not approved of by Desaguliers, who considered a jerking motion preferable.[3] This engine made

[1] *Experimental Philosophy*, Vol. II., p. 470. In the first edition, published in 1744, he says, "as it worked above twenty years ago." The same words are repeated in the third edition published in 1763. Dr. Stukeley visited Griff in 1725, and called upon Beighton, who was engaged with his map. He gives a short notice of the Griff engine, which he says, "works with a vast power from the atmosphere pressing into a receiver exhausted of air by vapour and then condensed." [*Itinerarium Curiosum*, by William Stukeley, M.D., 2nd. ed. London, 1776. Cent. II. p. 19.]

[2] This form of self-acting gear is often called "Beighton's," but so far as the writer is aware Desaguliers does not refer to it as such

[3] *Experimental Philosophy*, Vol. II., p. 477. "There is a way of opening and shutting the injection-cock," he says, "different from this with the quarter wheels; more used, and I think a great deal better; because it moves with a jerk, which is the best way to overcome friction."

sixteen strokes per minute. Mr. Beighton found by experiment that it worked well with the pressure of

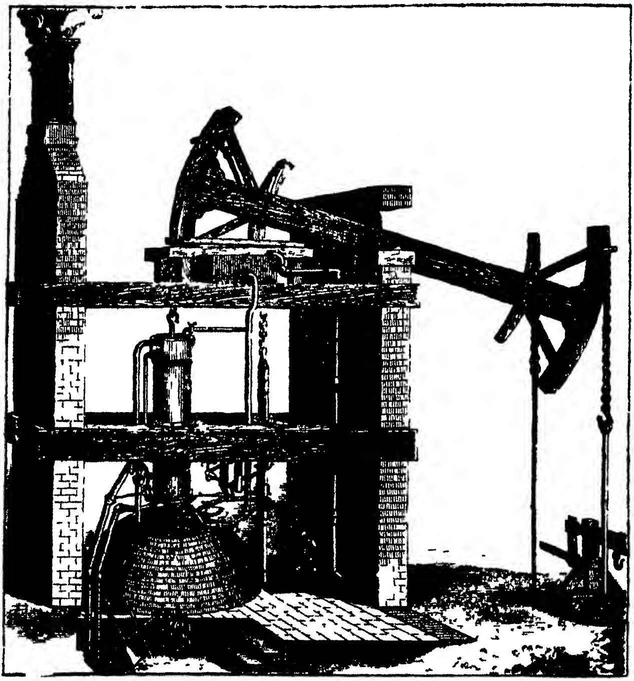

FIG. 20.—ATMOSPHERIC ENGINE AT GRIFF, IN WARWICKSHIRE, ABOUT 1723.

the steam in the boiler one pound above the pressure of the atmosphere.[1]

[1] *Experimental Philosophy*, Vol. II., p. 472.

The water was raised from a depth of fifty yards, in three lifts as shown in the margin (Fig. 22). The object of dividing the pump-work into three parts was to ease the pressure on the pipes. "If we endeavour to do it in one lift," says Desaguliers, "we shall burst the lower pipes, unless they be of iron, which will be costly; but

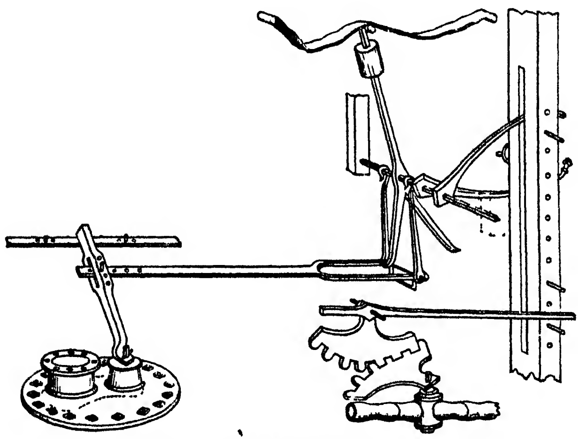

FIG. 21.—VALVE-GEAR OF GRIFF ENGINE.

wood will serve very well if we divide the work into three lifts of fifty foot each." [1]

Regarding the performance of this engine, Desaguliers states that it "did discharge as much water as did before employ more than fifty horses, at an expense not less than 900*l.* a year; whereas the fire in coals,

[1] *Experimental Philosophy*, Vol. II. p. 478.

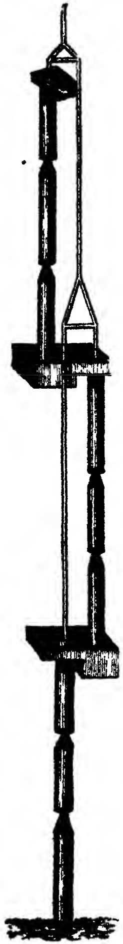

FIG 22.—PUMPS OF GRIFF ENGINE.

attendance, and repairs, did never cost more than 150*l.* a year in this engine."[1]

In treating of the power of the engine, Desaguliers incidentally mentions the method of calculation followed by Newcomen. "Mr. Newcomen's way of finding it," he says, "was this: From the diameter [of the cylinder] squared he cut off the last figure, calling the figure on the left hand long hundreds, and writing a cipher on the right hand, called the number on that side pounds; and this he reckoned pretty exact as a mean, or rather when the barometer stood at 30, and the air was heavy. Then he allowed between a third and a fourth part for what is lost in the friction of the several parts and for accidents: and this will agree pretty well with the work at Griff engine, there being lifted at every stroke between two-thirds and three-fourths of the weight of the atmospherical column pressing on the piston."[2]

Though the metalliferous mines in some districts were much in want of more powerful draining machinery, the high

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[1] *Experimental Philosophy*, Vol. II. p. 482. [2] *Ib.*

price at which alone they could obtain a supply of fuel, operated as a great check to the employment of fire engines. The second engine in Cornwall was erected at Wheal Fortune, in Ludgvan, in 1720.[1] Shortly afterwards another engine was built near the North Downs, at Huel Rose, seven or eight miles from Truro, by Mr. Joseph Hornblower, who was sent into Cornwall on purpose.

Hornblower was a native of Bromsgrove, in Worcestershire, or its vicinity. He was by profession an engineer. "How he became in any way connected with Newcomen," says Mr. Cyrus Redding, a descendant of Hornblower, "must have arisen from the latter being at Bromsgrove, where he, Newcomen, visited a Mr. Potter who got him to build one of his newly-invented engines at Wolverhampton, in 1712."[2]

The cost of coal in Cornwall, however, presented such an obstacle to the use of fire engines, that few were employed there, previous to the remission by Government of the duty on coal consumed by mine-draining engines. According to Price there was only one fire engine at work in this county about 1740.[3]

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[1] "The Statistics of the Copper Mines in Cornwall," by Sir Charles Lemon, Bart., in the *Journal of the Statistical Society of London*, Vol. I., p. 66.

[2] *Yesterday and To-day*, by Cyrus Redding, London, 1863, Vol. I., pp. 128-9.

[3] *Mineralogia Cornubiensis*, London, 1778. Introduction, p. xiv.

CHAPTER IX.

CONTINUED SPREAD OF THE USE OF ATMOSPHERIC ENGINES.—DEATH OF NEWCOMEN.

THE first atmospheric engine on the Continent was built by a Mr. Potter, an Englishman, at Königsberg, in Hungary, about 1723. It is described and figured by Leupold, in the second volume of his *Theatrum Machinarum Hydraulicarum*, published at Leipzic in 1725.[1] The engine was very much admired, and Potter

[1] *Theatri Machinarum Hydraulicarum*, Tom. II., Leipzig, 1725, p. 94.

Leupold also describes a form of single-acting high-pressure steam engine, but though proposed and even tried at different times, this class of engine was of an imperfect type and never came into use.

The steam engine invented by Sir Samuel Morland in 1682, which appears to have been designed for working his patent forcing-pump, probably belonged to this class. The only mention he makes of it occurs in a small treatise preserved in the Harleian collection of manuscripts at the British Museum, No. 5771, entitled, *Élévation des Eaux par toute Sorte de Machines réduite à la Mesure au Poids et à la Balance, présentée à sa Majesté Très Chrétienne par le Chevalier Morland,*

was regarded as its inventor. Leupold himself had not seen it, and he states that some parts of the sketch which he gives must be understood to be rather his own idea than an actual representation of the mechanism.

A curious advertisement from the *Newcastle Courant* of January 27th, 1724, shows that an agency for the erection of atmospheric engines was established in the North of England by the patentees at this date. It is as follows:—

"This is to give notice to all gentlemen and others, who have occasion for the fire engine or engines for drawing of water from the collieries, &c., to apply to Mr. John Potter, in Chester-le-street, who is empowered by the proprietors of the said fire engines to treat about the same."[1]

Whether the above Mr. Potter was the individual who erected the engine in Hungary we are not informed, but it seems highly probable that he was.

No records of any engines built by Potter in the Newcastle-on-Tyne district have been preserved, so far

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Gentilhomme Ordinaire de la Chambre Privée, et Maistre de Méchaniques du Roy de la Grande Bretagne, 1683.

Sir Samuel Morland had been sent to France to assist the French king with his water-works, and his idea of employing high-pressed steam to raise water (like that of Hautefeuille to use gunpowder, and probably also that of Huyghens to use the atmospheric pressure acting on a piston) was doubtless brought forward in connection with the many schemes suggested for supplying Versailles with water from the Seine, which was at length accomplished by the erection of the Great Machine of Marly.

[1] Brand's *History of Newcastle-upon-Tyne*, Vol. II., p. 686, note.

as the writer is aware, but we are fortunate enough to have full particulars regarding one erected by him at Edmonstone Colliery, in Midlothian, Scotland, brought to light by the industry of Mr. Bald. The following is the account given by Mr. Bald regarding the discovery of these interesting documents and their contents:—

"Understanding that a steam-engine had been erected at an early period at Edmonstone Colliery, in the county of Midlothian, an application was made by a gentleman to the present proprietor, John Wauchope, Esq., inquiring if he could throw any light on this subject.

"Mr. Wauchope instantly attended to the application, and, in a very polite manner, sent from the family records those papers which still remained relative to the erecting of the steam-engine at Edmonstone Colliery. They are authentic documents, and I therefore feel much indebted to that gentleman for his liberal communications, and still more so for his granting me permission to take what notice of these papers I thought proper.

"The first of these papers is dated May, 1725. It is 'A license granted by the Committee in London, appointed and authorised by the proprietors of the invention for raising water by fire, to Andrew Wauchope, of Edmonstone, Esquire.'

"This license states, that as the colliery at Edmonstone could not be wrought by *reason of water*, liberty is granted to erect *one* engine, with a steam cylinder nine feet long and twenty-eight inches diameter, according to the method and manner now used at the coalwork of Elphingstone in Scotland; for which license a royalty of 80*l.* per annum was to be paid for eight years. . . .

"The second of these papers contains an account of the expense of the materials of this machine, exclusive of the engine-house, the amount of which is 1,007*l.* 11*s.* 4*d.* This account contains every minute article furnished; it is a curious and valuable paper, dated 1727. . . .

"The steam-cylinder, some of the working barrels, and all the buckets and clacks, were made of brass, somewhere beyond London. The common pumps for the pit were of elm, of a bore nine inches diameter, and made out of the solid tree, hooped with iron, and brought from London. The boiler top was made of lead. . . .

"That these engines were very little understood, and very difficult to be kept in order, appears from an agreement entered into betwixt the tacksman of one of Mr. Wauchope's collieries, and the engineers who erected the steam-engine [viz. John Potter, engineer at Chester in the Street, and Abraham Potter, his brother-german].[1] It is there stipulated, that the engineers were to have no less a sum than 200*l.* a year to keep the engine going, and were, besides, to have the half of the clear profits of the colliery, after paying all expenses.

"It was also stipulated, that if the engineers could not make the engine draw water, so as to place the colliery in working order, they were to have liberty of taking away all the materials furnished by them, and to be paid a reasonable allowance for their pains and charges."[2]

The first of the above documents contains a clause which is of special interest, as it sets at rest the question of the date of the expiration of the patent privilege. It is therein granted to Andrew Wauchope, his heirs, &c., "to hold, use, and exerce the samen engine, so to be erected, from and after the 24th day of June next ensuing the date hereof [May, 1725], for and during, and until the full end and period of the said John Meres and proprietors aforesaid, their grant and license

[1] By the agreement Abraham Potter was appointed steward and factor of the colliery for the remaining term of the lease.

[2] *View of the Coal Trade of Scotland*, pp. 18, *et seq.*

for the sole use of said engine, being eight years complete next following and ensuing."[1] We thus see that the patent right to Newcomen's engine expired in 1733, or precisely thirty-five years from 1698, the date of the original patent granted to Savery.

Of the mechanism of the Edmonstone engine we have no particulars, but we have very good accounts of several atmospheric engines belonging to this period, accompanied by drawings.

The first of these is given in Stuart's *Anecdotes of Steam Engines*, and is stated to be taken from "an exceedingly rare and curious print, published in 1725."[2] The improved method of feeding the boiler with a portion of the hot water issuing from the bottom of the cylinder is clearly shown as in use. The introduction of this improvement is described by Desaguliers as follows:—

"It had been found of benefit to feed the boiler with warm water coming from the top of the piston rather than cold water, which would too much check the boiling, and cause more fire to be needful. But after the engine had been placed some years, some persons concerned about an engine observing that the injected water as it came out of the eduction-pipe was scalding hot, when the water coming from the top of the piston was but just lukewarm, thought it would be of great advantage to feed from the eduction

[1] *View of the Coal Trade of Scotland*, pp. 150-1. These interesting documents are printed in full in the appendix of Mr. Bald's book.

[2] *Anecdotes of Steam Engines*, Vol. I., pp. 174-8.

or injected water, and accordingly did it, ... which gave a stroke or two of advantage to the engine." [1]

Another account of the atmospheric engine at this period is given by Switzer, in his treatise on *Hydrostatics and Hydraulics*, published in 1729. The engine which he describes differs, he says, in no essential part from that set up at York Buildings [in 1726], which he characterizes as a "Noble Engine," summing up in a great measure the improvements that had been made on the fire engine by Mr. Newcomen.[2]

The engine figured and described by M. de la Motraye, in 1732, has been supposed to be the York Buildings engine, but it seems doubtful whether it is not a copy of the engine in the print above-mentioned, published in 1725, to which it bears a remarkable resemblance. It is shown in Fig. 23. It is noteworthy that the buoy arrangement of self-acting gear, employed by Newcomen in his first engines, is still adhered to in this case.[3]

[1] *Experimental Philosophy*, Vol. II., p. 481. This improvement has been ascribed by some writers to Beighton, but Desaguliers does not mention him in this connection See also *Ibid.* p. 534.

[2] *Hydrostaticks and Hydraulicks*, Vol. II., p. 335, *et seq.* See also Vol. I., Preface, p. vi.

Dr. Allen, writing in 1730, mentions that "for the working of the [atmospheric] engine at York Buildings the article of coals is at least 1,000 pounds a year." [*Specimina Ichnographica; or, A Brief Narrative of Several New Inventions and Experiments*, by John Allen, M.D., London, 1730, p. 14.]

[3] "The new fire engine," says M. de la Motraye, "is placed between the water engines of London Bridge, and another towards Chelsea."

We have now arrived at the period which witnessed the close of the career of Mr. Newcomen. From the terms in which Switzer refers to him, he was evidently still alive when Switzer wrote his treatise on Hydrostatics. He is stated to have died in London in 1729, of a fever, after a fortnight's illness.[1]

The following passage, written by Dr. Allen in 1730, contains, perhaps, the only contemporary allusion to this event: "It is now more than thirty years since the engine for raising water by fire was first invented by the famous Captain Savery, and upwards of twenty years that it received its great improvement by my good friend, *the ever-memorable Mr. Newcomen, whose death I very much regret.*"[2]

Newcomen had lived to see his invention widely introduced, and on all occasions with the greatest success. He would doubtless have received more of the pre-eminent distinction to which he was entitled, during his lifetime, had he not acquiesced in his great

On the same plate one of Savery's engines is shown, but it appears to be taken from Savery's figure of his engine working in a mine. [*Voyages en Anglois et en François, D'A de la Motraye en diverses Provinces, &c.* La Haye, 1732, p. 360.] See also Stuart's *Anecdotes of Steam Engines*, Vol. II., p. 622.

[1] Paper by Mr. T. Lidstone, Dartmouth, read before the Royal Archæological Institute of Great Britain and Ireland, at Exeter, in 1873. *Archæological Journal*, Vol. XXX., p. 437.

[2] *Specimina Ichnographica; or, A Brief Narrative of Several New Inventions and Experiments*, by John Allen, M.D., London, 1730, p. 14. Reprinted by George E. Eyre and William Spottiswoode, London, 1858.

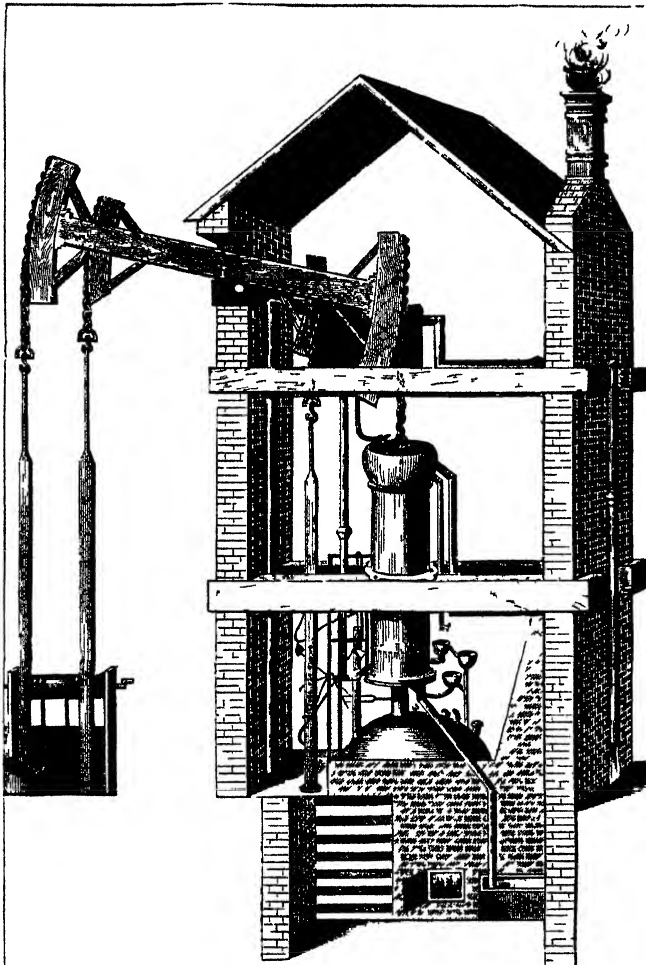

FIG 23 – ATMOSPHERIC ENGINE, 1782 (A de la Motraye)

invention being allowed to pass for an improvement upon Savery's engine.

The admiration which the performances of the atmospheric engine elicited from intelligent observers, is exhibited in the following notices of it taken from the pages of some early writers.

Belidor, the celebrated author of *Architecture Hydraulique*, in the second volume, which was published in 1739, gives a detailed description, accompanied by numerous excellent figures, of an atmospheric engine which had been erected by English engineers at a coal mine at Fresnes, near Condé (Fig. 24). He had paid several visits to this engine for the express purpose of describing it. The cylinder of the engine was thirty inches in diameter. Previous to the erection of this engine, fifty horses and twenty men, working day and night, had been required to raise the water from the mine, whereas the engine with a single attendant, in forty-eight hours working, cleared the colliery of water for a whole week. Belidor, as was to be expected, ascribes the invention of the fire engine to Savery, but remarks that in one of the letters on the subject which he had received from the Royal Society, Mr. Newcomen had been mentioned as having greatly contributed towards bringing it to its present state of perfection. After completing the description of the engine, Belidor pronounces the following high encomium upon it:—

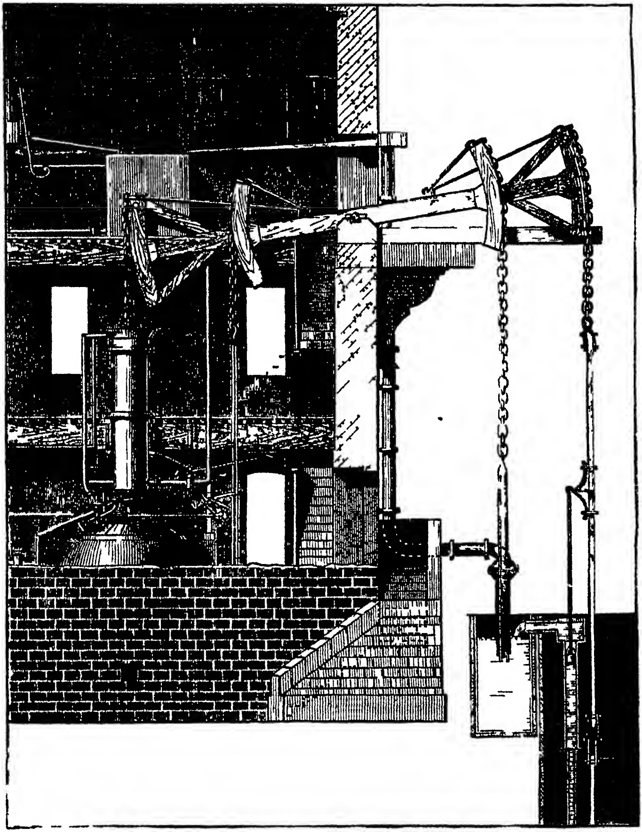

FIG 24 —ATMOSPHERIC ENGINE AT FRESNES NEAR CONDÉ 1739 (Belidor)

" We must avow that this is the most marvellous of all machines, and that there is not a single other of which the mechanism has so much resemblance to that of animals Heat is the cause of

its motion, a circulation takes place in its different tubes like that of the blood in the veins; it has valves which open and close at the proper moment; it feeds itself, it rejects what it has used at regular intervals, it draws from its own work everything that it requires for its support."[1]

"An Account and Draught of the Fire Engine" appeared in the *Universal Magazine* for September, 1747, in which the writer eulogizes the invention in the following terms:—

"It is the most admirable, curious, and compounded machine, amongst all those inventions which have been owing to modern philosophy, and affords the greatest advantages to mankind; as could be exemplified from the waterworks near Chelsea, on the west of this great city, and again by those lately erected near Stratford, in Essex, on the east of London, which are able to supply the adjacent country, several miles in circumference, with the necessary provision of good and wholesome water at a moderate charge, which before was wanting both for household service and the danger and loss by fires. To this I could add the impossibility of working several collieries without its assistance, as the proprietors of Elsick, Heaton, Biker, &c., near Newcastle-on-Tyne, can bear me witness. This engine is also improveable for many other great and valuable uses."

In his *Descriptive poem addressed to two ladies at their return from viewing the mines near Whitehaven*, in Cumberland, published in 1755,[2] Dr. Dalton thus refers to the working of the fire engine:—

[1] *Architecture Hydraulique*, par M. Belidor. Paris, 1739. Vol. II., p. 324.

[2] In a note appended to page 11 of the poem we are informed that there were now four fire engines employed in draining this colliery. The mines at Whitehaven were the deepest coal mines yet wrought, having

"A different scene to this succeeds:
The dreary road abruptly leads
Down to the cold and humid caves,
Where hissing fall the turbid waves.
Resounding deep thro' glimmering shades
The clank of chains your ears invades.
Thro' pits profound, from distant day
Scarce travels down light's languid ray.
High on huge axis heav'd, above,
See balanc'd beams unweary'd move!
While pent within the iron womb
Of boiling caldrons, pants for room
Expanded Steam, and shrinks, or swells,
As cold restrains, or heat impels,
And, ready for the vacant space,
Incumbent Air resumes his place,
Depressing with stupendous force
Whate'er resists his downward course.
Pumps moved by rods from ponderous beams
Arrest the unsuspecting streams,
Which soon a sluggish pool would lie;
Then spout them foaming to the sky.
Sagacious Savery! Taught by thee,
Discordant elements agree,
Fire, water, air, heat, cold, unite,
And listed in one service fight,
Pure streams to thirsty cities send,
Or deepest mines from floods defend.
Man's richest gift thy work will shine;
Rome's aqueducts were poor to thine!"[1]

attained to a depth of 130 fathoms at this date. They were supposed to be the deepest mines in the world, *below the level of the sea. Ibid.* p. 13, note.

[1] Desaguliers thus summarizes the great superiority of the atmospheric engine over the once celebrated machine of Marly, built, in 1682,

Dr. Robison, a contemporary of Watt, and author of *A System of Mechanical Philosophy*, after describing the atmospheric engine, thus continues:—

"Such is the state in which Newcomen's steam-engine had continued in use for sixty years, neglected by the philosopher, *although it is the most curious object which human ingenuity has yet offered to his contemplation*, and abandoned to the efforts of unlettered artists. Its use has been entirely confined to the raising of water."[1]

to supply the King of France's gardens at Versailles with water:—"It is said that the machine at Marly cost above eighty millions of French livres, which is above four millions of pounds sterling. Some of the largest of our fire engines, at present in use in England (1744), will raise as much water to the same height, and not cost above ten thousand pounds."—*Experimental Philosophy*, Vol II., p. 531.

[1] *A System of Mechanical Philosophy*, Edinburgh, 1822. Vol. II., p. 103.

CHAPTER X.

THE ATMOSPHERIC ENGINE DURING THE PERIOD WHICH INTERVENED BETWEEN NEWCOMEN AND WATT.

IN so far as the history of the evolution of the steam engine is concerned, the period intervening between the death of Newcomen and the era of Watt might almost be allowed to pass without notice. It is true that towards the end of this time the atmospheric engine was brought to perform its work with a less expenditure of fuel, but as regards the machine itself, its mechanism remained almost exactly in the condition given to it by Newcomen, until the date of its transformation into the modern steam engine by the genius of Watt. During this interval, however, great changes occurred in the materials used in the construction of the engine and its appendages; its size was largely increased; its use much extended; matters which are of themselves possessed of sufficient interest to warrant some account of them being given.

Since the revival of the iron trade of Great Britain, consequent upon the successful application of mineral fuel to the smelting of the ore, a process first practised upon a large scale at Coalbrookdale ironworks, and commenced about 1730–5,[1] the increased abundance and cheapness of this metal led to a great extension of its use. The changes which subsequently took place in the materials used in the construction of atmospheric engines, present a remarkable example of the spread of the use of iron. It is curious to find Dr. Desaguliers, in 1744, raising his voice against the employment of cast-iron cylinders. "Some people," he says, "make use of cast-iron cylinders for their fire engines, but I would advise nobody to have them; because, though there are workmen that can bore them very smooth, yet none of them can be cast less than an inch thick, and therefore they can neither be heated nor cooled so soon as the others, which will make a stroke or two a minute difference, whereby an eighth or a tenth less water will be raised. A brass cylinder of the largest size has been cast under one-third of an inch in thickness, and at long run the advantage of heating and cooling quick, will recompense the difference in the first expense; especially when we consider the intrinsic value

[1] The earlier date (1713) given by Scrivenor in his *History of the Iron Trade* (London, 1854, p. 56), appears to be incorrect. See *Industrial Biography*, by Samuel Smiles (London, 1876, p. 83). The date which we have adopted is that given by Mrs. Abraham Darby in Dr. Percy's *Metallurgy of Iron and Steel*, ed. 1864, p. 886, *et seq*.

of the brass."[1] The greater cheapness and superior strength of iron, however, carried the day; and the brass cylinders, copper boilers, and wooden pumps, all gradually became things of the past.[2] Coalbrookdale ironworks for a long period continued the chief source from which the supply of the new material was obtained.

We have already seen that little progress was made in the introduction of the atmospheric engine into Cornwall at the date of its invention. Since this time, however, considerable changes had occurred. The patent right had now expired; cheaper materials were used in the construction of the engine; and, more important than either, the duty chargeable on coals consumed by mine-draining engines in Cornwall was remitted. It appears that previous to the year 1730, a petition having this object was drawn up and presented to Government by the mine-adventurers, but it was not till 1741 that an Act of Parliament was obtained by which the duty was taken off.[3] From only one engine in use at this date the number rapidly increased.

Dr. Borlase, writing in 1758, mentions a considerable number, and remarks upon the great sizes which they were now attaining to. The engine that was at the

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[1] *Experimental Philosophy*, Vol. II., p. 536.

[2] The wooden beam, or lever, held its ground longer, but at length it too was replaced by one of iron.

[3] Pole on the *Cornish Pumping Engine*, pp. 14, 15. The amount of the duty was five shillings a chaldron.

Pool Mine in 1746, he says, had a cylinder of but three feet diameter, from the outer edge; "but they make them much larger now .... A cylinder of forty-seven inches at Ludgvan-lez work, in the parish of Ludgvan, making about fifteen strokes in a minute, usually drew through pit barrels of fifteen inches diameter, from a pump thirty fathoms deep, about an hogshead at each stroke, that is, fifteen hogsheads of water in each minute." At Herland (or Drennack) Mine, in the parish of Gwinear, there was an engine with a cylinder seventy inches in diameter. At North Downs Mine, in the parish of Redruth, there were two engines. At Pitt-louran Mine, Resnorth, there were also two. And there were engines at Polgooth, Huel-rith, Bullen-garden, Dolcoath, the Pool, Bosproual, Huel-rôs, and some other mines.[1]

Many atmospheric engines, some of very large size, were built at collieries in the Newcastle-on-Tyne district at this period. Mr. William Brown, of Throckley, near Newcastle-on-Tyne, an eminent colliery viewer of that time, played a conspicuous part in the erection of engines. "In 1756, upon getting the management of Throckley Colliery, he built one there—then a great rarity. In 1757, one at Birtley North Side, one at Lambton, and one at Byker. In 1758, two at Walker, and one at Bell's Close. In 1759, one at Heworth. In

[1] *The Natural History of Cornwall*, by William Borlase, A.M., F.R.S., Oxford, 1758, pp. 173, 175.

1760, two at Shire Moor, and one at Hartley. In 1762, one at Oxclose, one at Beamish, and one at Benwell (which had not only three boilers, but 24-inch wooden pumps, formed of staves). In 1763, one at West Auckland, with wooden pumps of 18 inches diameter. In 1764, one at North Biddick, one at Low Fell, and three in Scotland (viz., one at Borrostowness, one at Pittenweem in Fifeshire, and one near Musselburgh). In 1766, one at Lambton. In 1772, one at Fatfield. In 1775, two at Willington, and one at Washington (with its house contrived to take in a second). In 1776, one at Felling."[1]

A very large atmospheric engine was built at Walker Colliery in 1763. It is referred to in the local records of Newcastle-on-Tyne in the following terms.—

"A fire engine cylinder was landed at Wincomblee coal staith, on the river Tyne, for the use of Walker Colliery, which surpassed everything of the kind which had been seen in the North. The diameter of the bore measured upwards of seventy-four inches, and it was ten-and-a-half feet in length. Its weight, exclusive of the bottom and the piston, was six-and-a-half tons, containing altogether between ten and eleven tons of metal. The bore was perfectly round and well polished. It was considered a complete piece of work, and did honour to Coalbrookdale foundry in Shropshire, where it was manufactured. When this engine, to which the cylinder was attached, was completed, it would have a force to raise 307 cwts. of water."[2]

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[1] *View of the Coal Trade of the North of England*, by Matthias Dunn, Newcastle-upon-Tyne, 1844, p. 41.

[2] *The Local Historian's Table Book*, by M. A. Richardson, Newcastle-upon-Tyne, 1842, Historical Division, Vol. II., p. 109. It is

Regarding this engine, M. Jars, a highly intelligent Frenchman, who visited the Newcastle-on-Tyne district in 1765, informs us that it was the largest in the North of England, and perhaps the largest yet made in Europe. To provide the necessary steam, four very large boilers were employed, of which three were always in use. The tops of the boilers were of lead, with the exception of the one immediately under the cylinder, the top of which was of copper. M. Jars remarks that it was no longer customary to employ two different materials in the construction of boilers, but to make them entirely of iron; and that in some cases the boiler was not placed under the cylinder, but beside it. The piston, which was of iron, was packed with hemp rope, and the usual stratum of water was kept on the top of it. On account of the large size of the cylinder three water-jets were required to effect the condensation of the steam. The pumps, which were in three lifts, raised the water eighty-nine fathoms,[1] at which point it was delivered into a water-drift, which discharged it into the river Tyne. All the pumps were

stated by Mr. Smiles [*Lives of the Engineers—Early Engineering*, ed. 1874, p. 152] that this engine was built by James Brindley. The reference which is given, however, does not seem to support the statement. It would appear from Wallis' *History of Northumberland*, Vol. I., p. 133, that it was probably built by William Brown of Throckley.

[1] The total depth of the mine was 100 fathoms. This was the greatest depth attained in the Newcastle-on-Tyne district at this date, as we are informed by M. Jars.

made of cast iron. The engine consumed two-and-a-half chaldrons (six-and-a-half tons) of coals per day. The stroke of the piston and pumps was six feet, and from eight to ten strokes were made per minute.[1]

About this time the celebrated civil engineer, John Smeaton, began to turn his attention to the subject of atmospheric engines. Among his reports is to be found a description of a "portable fire-engine" (Fig. 25) invented by him in 1765, at the instance of the Earl of Egmont.[2]

In designing an engine for the New River Company, in 1767, Smeaton took occasion to depart considerably from the proportions usually adopted in the construction of engines, hoping thereby to obtain superior results. He made the cylinder long and narrow, its diameter being only eighteen inches, while the stroke of the piston was nine feet. Being surprised to find the effect of the alteration not at all to answer his expectation, he resolved to make himself master of the subject.[3] To accomplish this he determined to construct an experimental model at his house at Austhorpe, and previous to doing so he began to collect information regarding engines then in use. In 1769 he is stated to have obtained a list of 100 engines which had been erected

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1 *Voyages Metallurgiques*, par feu M. Jars. A Lyon, 1774, Vol. I. pp. 195-7.

2 Vol. I., p. 223.

3 Farey on the *Steam Engine*, p. 158, note.

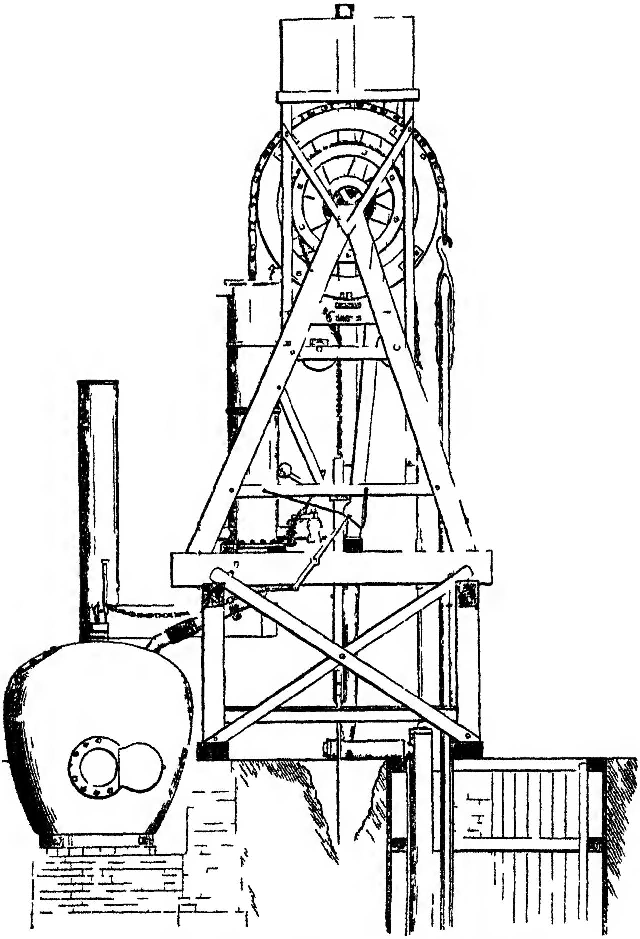

Fig 25—Smeaton's Portable Atmospheric Engine 1765

at collieries in the Newcastle-on-Tyne district.[1] The list subjoined, taken from the books of Mr. William Brown of Throckley, and bearing the same date, is doubtless either the original or a copy of that referred to :—

	No	Diameter of Cylinder.		No.	Diameter of Cylinder.
Elswick	2	28, 27	Throckley . .	4	36, 18 48, 60
Jesmond . . .	4		Wylam	2	47, 60
Byker	6	42, 42, 60	Gosforth	1	
Heaton	4		Workington. . .	1	28
Benton	5	60	Grey Southen . .	1	24
Tynemouth Moor	4	60, 42, 75, 70	Whitehaven. . .	4	28, 36, 42, 42
Plessey	1	32	Parton Do. . . .	1	42
Choppington . .	1	16	Bushblades . . .	2	42, 52
Black Close . .	1	13	Rise Moor . . .	1	60
Eshott	1		Ouston . . .	1	48
Felkington. .	1	20	South Moor. . .	1	47
Duddingston, N B.	1	66	Ravensworth . .	3	48
Borrostowness .	2		Gateshead Fell. .	1	
Newbiggin. . .	4	42, 42, 44, 60	Salt Meadows .	1	32
Hartley . . .	2	42 62	Heworth. . . .	2	52, 72
Unthank . . .	1	36	North Biddick .	2	62
Chirton	1	48	Washington. . .	2	62
Walker	2	78, 72	Chartershaugh. .	1	36
West Denton . .	2	36, 38	Lambton . .	2	42, 64
East Denton . .	1	60	South Biddick . .	2	
Benwell . . .	1	75	Newbottle . . .	2	36, 48
Lemington. . .	1	42	Pensher, Tempest.	2	
Auckland . . .	1	48	Morton Hill . .	2	
Nottingham . .	1	60	Black Fell . . .	1	
Norwood . . .	1	13	Chester Burn . .	1	28
Shilbottle . . .	1	42	Fatfield	2	62, 47
Newburn . . .	1		Fallowfield Lead-mine	1	42
				99[2]	

It appears that many engines in the list had been worn out and given up, and that the number of engines actually at work was fifty-seven. The average perform-

[1] Farey on the *Steam Engine*, p. 233.

[2] *View of the Coal Trade of the North of England*, by Matthias Dunn, p. 24.

ance of fifteen of these engines, of different sizes, was computed by Mr. Smeaton to be 5·59 millions of pounds raised one foot high by the consumption of one bushel (eighty-four pounds) of coal. The average pressure [1] on the piston was 6·72 pounds per square inch.[2]

Smeaton collected minutes regarding eighteen large engines at work in Cornwall about the same period. Eight of these engines had cylinders from sixty to seventy inches in diameter. Mr. Jonathan Hornblower and Mr. John Nancarrow are stated to have been the principal builders of them.[3] The above engines, however, were only a small proportion of the total number which had been erected in the county. Price, writing a few years later (1778), informs us that above sixty engines had been built since the remission of the duty on coals, and that more than half of them had been rebuilt or enlarged in the diameter of their cylinders.[4]

The model engine at Austhorpe was set to work in the winter of 1769. It had a cylinder of ten inches diameter, and a stroke of three feet two inches. With this engine Smeaton conducted a series of experiments, from which he deduced rules for the best proportions of the parts of atmospheric engines, and in 1772 he

[1] *i.e.* effective atmospheric pressure.

[2] Farey on the *Steam Engine*, p. 234.

[3] *Ibid.*, p. 237.

[4] *Mineralogia Cornubiensis*, Introduction p. 14. Price states that by means of Newcomen engines the miners were enabled to sink to twice the depth they could formerly do by any other machinery. [*Ibid.*, p. 308.]

constructed a table embodying the results of his experiments, and exhibiting the best proportions for engines of all sizes up to seventy-two inch cylinders.[1]

From this date he began to design a number of engines, some of large size. The first of these was built at Long Benton Colliery, near Newcastle-on-Tyne, in 1772.[2] It had a cylinder fifty-two inches in diameter. Two others were built in 1775,—one at Chacewater, Cornwall, with a cylinder seventy-two inches in diameter, and the other at Cronstadt, near St. Petersburg, having a sixty-six inch cylinder.[3] The engine at Chacewater (Fig. 26) was the most celebrated of Smeaton's engines. It worked with a nine-feet stroke, and made nine strokes per minute. It had three boilers, each fifteen feet in diameter, one placed beneath the cylinder and one on each side of the engine-house. The lever of this engine was built of twenty fir beams, two in width and ten in depth.

Smeaton also designed an engine with a 60-inch cylinder for Gateshead Park Colliery, near Gateshead-on-Tyne, in 1778; and an engine with a 72-inch cylinder (like that at Chacewater) for Middleton

[1] Farey on the *Steam Engine*, pp. 158, 166, 183.

[2] *Ibid.*, pp. 134, 172, 235, note. The cylinder of this engine appears to have been replaced afterwards by one of Watt's new cylinders.—See *ibid.*, p. 321.

[3] Smeaton's *Reports*, Vol. II., pp. 347, 360. The Cronstadt engine was employed in draining a dock.

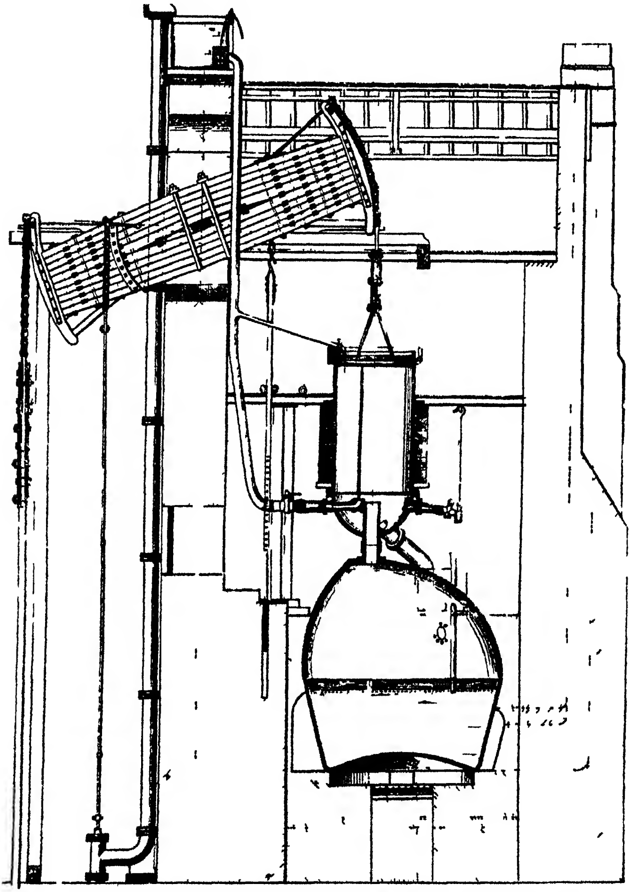

FIG 26 —ATMOSPHERIC ENGINE AT CHACEWATER, CORNWALL 1775

Colliery, near Leeds, in 1780.[1] The duty performed by Smeaton's improved engines, is stated to have been 9,450,000 lbs. raised one foot high by the consumption of a bushel (84 lbs.) of coal.[2]

Previous to the time when Smeaton began to direct his attention to the atmospheric engine, several attempts had been made to derive a rotatory motion from the reciprocating movement of the engine.[3] The engine being single-acting, it is not surprising that

[1] Farey on the *Steam Engine*, p. 242, note.

[2] *Ibid*, pp. 173, 235, note. Taylor's *Records of Mining*, p. 153.

[3] In Jonathan Hulls' pamphlet, published in 1737 [see *post*, p. 168] a plan was proposed for effecting this for driving a paddle-wheel. In the *Philosophical Transactions* for 1758, Keane Fitzgerald, F.R.S., described an arrangement for working rotating mine-ventilators by means of the fire engine. It appears to have been applied at Walker Colliery, near Newcastle-on-Tyne, the apparatus not only working two ventilators, but also assisting to turn a wheel for raising coals out of the pit.—See Wallis' *Natural History and Antiquities of Northumberland*, London, 1769, Vol. I., p. 128.

In 1763 a Mr. Joseph Oxley took out a patent for a method of applying the fire engine to the raising of coals. Two of his machines were erected at Hartley Colliery—the second and improved one in 1765. [Richardson's *Local Historian's Table Book*, Historical Division, Vol. II., p. 130.] M. Jars went to see the machine the same year, but it was broken down at the time. It is curious to find him observing that it would be better to lift the water of the fire engine on to a wheel for the purpose of turning a drum for raising the coal—a plan which was adopted in the district a few years afterwards. [*Voyages Metallurgiques*, Vol. I., pp. 207, 8.] Watt went to see it about 1768. He remarks that it went sluggishly and irregularly, having no fly-wheel. [Muirhead's *Life of Watt*, 2nd ed., p. 274.] See also Farey on the *Steam Engine*, p. 408.

little success attended the various efforts which were made. In the latter part of the eighteenth century, however, an indirect method of employing fire engines to raise the coals out of the pits came largely into use in the colliery districts. The engines were applied to raise water into an elevated cistern, after the manner proposed by Savery, and the coals were drawn by means of double water-wheels, having their buckets arranged in opposite directions. The first of these "water coal-gins," as the machines were called, was designed by Smeaton, in 1777, for the Prosperous pit, Long Benton Colliery. It was found to be a great improvement upon the horse-gins previously in use, doing the work of sixteen horses and four men.[1]

These useful but clumsy machines came rapidly into use,[2] but their career was short-lived; [3] though Smeaton was of opinion that this application of the fire engine was the best means of procuring rotative motion from it, and that "to confer *directly* the movements of rotation on the axis, would never practically become either useful or economical," [4]—an opinion doubtless perfectly sound in the then condition of the engine.

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[1] Smeaton's *Reports*, Vol. II. p 435. Farey on the *Steam Engine*, p. 297

[2] *The Coal Viewer and Engine Builder's Practical Companion*, by John Curr, Sheffield, 1797, p. 34.

[3] *The History and Antiquities of the County Palatine of Durham*, by William Fordyce, 1857. Vol. II. p. 682.

[4] *Life of James Watt*, by M. Arago, 2nd ed., Edinburgh, 1869, p. 60, note. See also Smiles' *Lives of the Engineers*, Boulton and Watt, London, 1874, p. 232, and Farey on the *Steam Engine*, p. 413, note.

CHAPTER XI.

JAMES WATT INVENTS THE SEPARATE CONDENSER, AND EMPLOYS STEAM INSTEAD OF THE ATMOSPHERE TO ACT ON THE PISTON.

WHILE Smeaton was engaged in bringing Newcomen's engine to the highest degree of perfection of which it was capable, Watt had been occupied in analysing the principles of its mechanism, and by a few brilliant strokes of genius had transformed the machine from an atmospheric engine into a steam engine.

It is obvious that all the cylinder and piston machines which we have been considering, in whatever respects they differed from each other, were merely variations of the same idea. They might all be comprehended under the one generic name of *vacuum engines.* In the first apparatus of the kind, suggested by Otto von Guericke, the vacuum was produced by pumping the air out of the cylinder. Huyghens attempted to obtain a vacuum by means of the explosion of gunpowder. Papin tried both of the

preceding methods, and then suggested the condensation of steam, as a means of producing a perfect vacuum at small cost. Newcomen, by supplying steam from a separate boiler, and by adding numerous highly ingenious devices, produced a working engine of great power and utility. Steam, however, was only employed in the engine as the best means of enabling a vacuum to be produced by its condensation. The properties of steam were at that time little understood: the economizing of it was a matter of secondary consideration. Even subsequent to the time when Smeaton had worked out the best proportions of the parts of the engine with a special view to the economy of steam, Newcomen's engine still continued to require an extravagant supply of fuel. Watt's earliest efforts, like those of Smeaton, were directed towards promoting economy of steam. His first and most original invention, was the discovery of an arrangement for producing a vacuum, immensely superior to that employed in Newcomen's engine. The scientific manner in which Watt set about his experiments with the "fire engine," and how Watt's improved engine was developed out of Newcomen's, will be seen from the following account of Watt and his inventions.

James Watt was born at Greenock, in Scotland, on the 19th of January, 1736. He received his education

in the academies of his native town. In June, 1754, being then eighteen years of age, he proceeded to Glasgow to learn the trade of mathematical instrument maker. Through Mr. George Muirhead, a kinsman of his mother, Watt was introduced to the notice and acquaintance of several of the professors of Glasgow University. On the advice of Dr. Dick he left Glasgow after a year's stay there, and set out for London in June, 1755, to acquire better instruction in the trade which he had adopted. In London he remained little over a year, leaving again for Scotland in the end of August, 1756. He was now desirous to establish himself in his trade in Glasgow, but neither being the son of a burgess, nor having served a regular apprenticeship, he was prohibited from setting up a workshop within the limits of the burgh. In this difficulty he found the patronage of the University of singular service. Within its classic precincts the corporation of the city had no control. By Midsummer, 1757, Watt had received permission to occupy an apartment and open a shop within the college walls, and also to use the designation of "Mathematical instrument maker to the University."[1]

Watt's connection with Glasgow University proved highly beneficial to him in several ways, not the least important being the intercourse which he enjoyed with professors and students possessed of philosophic tastes

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[1] Muirhead's *Life of James Watt*, 2nd ed., p. 42.

kindred to his own. Among these were Dr. Black, who had been appointed Professor of Anatomy in 1756, and Professor of the Practice of Medicine in 1757; and Mr. John Robison (afterwards Dr. Robison), with whom Watt became acquainted in the winter of 1758-9, at which time he was a student in the Natural Philosophy class.

Watt's attention was first directed to the subject of steam engines in the year 1759, by Robison, who threw out an idea of applying this power to the moving of wheel-carriages and other purposes. Robison, however, went abroad shortly afterwards, and the scheme was abandoned.[1]

About 1761, or 1762, Watt tried some experiments on the force of steam with a Papin's digester, and formed a species of steam engine by fixing upon it a syringe, one-third of an inch in diameter, with a solid piston, and furnished with a cock to admit the steam from the digester, or shut it off at pleasure, as well as to open a communication from the inside of the syringe to the open air by which the steam contained in the syringe might escape. He soon relinquished the idea of constructing an engine on this principle, being sensible, he says, that "it would be liable to some of the objections against Savery's engine, viz., the danger of bursting the boiler, and the difficulty of making the joints tight; and also that a great part

[1] Muirhead's *Life of James Watt*, 2nd ed., p. 74.

of the power of the steam would be lost, because no vacuum was formed to assist the descent of the piston." [1]

We have now arrived at the era of all others the most eventful in the history of the steam engine. In the winter of 1763-4,[2] a small model of Newcomen's engine belonging to the laboratory of the Natural Philosophy class in the University of Glasgow, was put into the hands of Watt to be repaired. The model (Fig. 27) was an exact copy of a real engine.[3] Its cylinder, which was of brass, was two inches in diameter and six inches stroke. The boiler was about nine inches in diameter. Watt's knowledge of atmospheric engines at this time, was derived from the writings of Desaguliers and Belidor. He set about repairing the model *as a mere mechanician*, and when this was done it was set to work The voracious appetite for steam possessed by the little machine astonished Watt. Its boiler, though apparently quite large enough, was unable to supply it. By blowing the fire it was made to take a few strokes. Watt's attention was fairly aroused by the difficulty of getting it to work; he proceeded to investigate the matter.

Having discovered a great error in Désaguliers' calculation of Beighton's experiments on the bulk of

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[1] Muirhead's *Life of James Watt*, 2nd ed., pp. 74–75. [2] *Ibid.*, p. 75.

[3] It is now preserved in the Hunterian Museum at Glasgow.

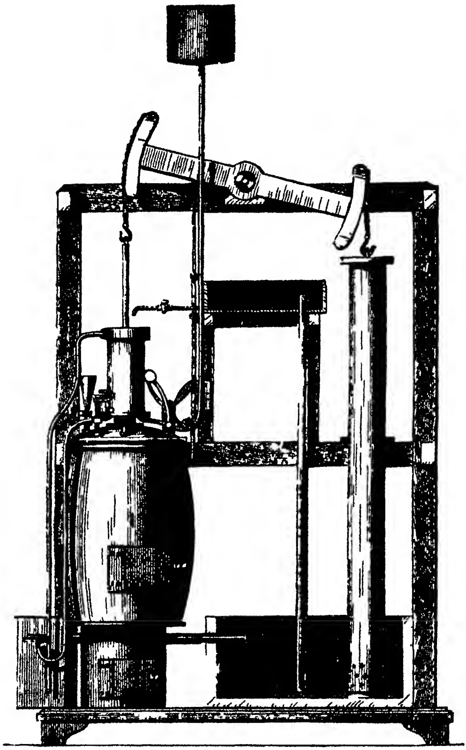

FIG. 27.—MODEL OF NEWCOMEN'S ENGINE, BELONGING TO GLASGOW UNIVERSITY. The boiler is not seen in the figure being inclosed in the outer casing or fire-box. The chimney is now wanting in the model.

steam,[1] Watt determined to work out the question for himself. He found that, at the temperature of boiling

[1] Muirhead's *Life of James Watt*, 2nd ed., p. 76. Desaguliers states the bulk of water to be 14,000 times less than when in the form of steam. [*Experimental Philosophy*, Vol. II., p. 469.] An earlier

water, steam was about 1,800 times more bulky than water. A boiler was then constructed which showed, by inspection, the quantity of water evaporated in a given time, and consequently exhibited the quantity of steam used by the engine at every stroke, which was found to be several times as much as would fill the cylinder.[1] It thus became clear that a very large proportion of the steam consumed was lost, by its condensation against the cold sides of the cylinder.

The great heat imparted to the injection-water by a small quantity of water in the form of steam, was matter of surprise to Watt.[2] By experiment he found that water, in the form of steam, could heat about six times its own weight of cold water to 212°. Having mentioned this fact to Dr. Black, the professor explained to him his doctrine of *latent heat*, of which this phenomenon afforded a striking illustration.[3]

By experiments which he tried upon the temperatures at which water boils under several pressures greater than that of the atmosphere, Watt ascertained that when the temperatures proceeded in an arithmetical, the elasticities proceeded in some geometrical ratio. This

investigator, Sir Samuel Morland, had estimated it at 2,000 times, which showed that his experiments had been conducted with a great amount of skill. [Harleian MSS., 5771, p 35.]

[1] *Ibid.*, p. 78.

[2] This fact had been remarked by Beighton also. [Desaguliers' *Experimental Philosophy*, Vol. II., p. 534.]

[3] Muirhead's *Life of Watt*, 2nd ed., p. 78.

pointed to the advantages which might be derived from using steam of higher temperature. On the other hand, as water boils *in vacuo* at less than 100°, it was obvious that a perfect vacuum could only be obtained below this temperature.

Thus, step by step, in a truly philosophic manner, Watt mastered the various problems connected with the use of steam. The conclusion to which he arrived was—*that to make a perfect steam-engine, it was necessary that the cylinder should be always as hot as the steam which entered it, and that the steam should be cooled down below* 100° *in order to exert its full powers.*[1]

How to compass these apparently irreconcilable requirements did not occur to Watt for some time, but early in 1765 the bright idea of employing *a separate vessel for the condensation of the steam*, flashed into his mind. It occurred to him, he says, "that if a communication were opened between a cylinder containing steam, and another vessel which was exhausted of air and other fluids, the steam, as an elastic fluid, would immediately rush into the empty vessel, and continue so to do until it had established an equilibrium; and if that vessel were kept very cool by an injection, or otherwise, more steam would continue to enter until the whole was condensed."[2] This, he at once saw, presented a solution of the problem satisfactory in every respect. The cylinder might be kept

[1] Muirhead's *Life of Watt*, 2nd ed. pp. 79, 87. [2] *Ibid.* p. 79.

as hot as it was desired, and the condenser as cold as was necessary; no steam be wasted, and a perfect vacuum be obtained at the same time. The immense economy which would result from such an arrangement was self-evident. The minor difficulties which presented themselves were quickly disposed of, and in a few days the invention was complete in Watt's mind.

In order to preserve the cylinder at a maximum temperature, Watt determined to exclude the external air from it, and to surround it with an atmosphere of steam. This he proposed to effect by inclosing it in a case, which was to be in free communication with the boiler (Fig. 28). The steam would thus constantly press upon the top of the piston, in the same way as the atmosphere had done previously in Newcomen's engine.[1] During the upstroke of the piston, by closing the valve communicating with the condenser and admitting steam into the bottom of the cylinder, the piston would be placed in equilibrium, and so be carried to the top of the cylinder by the weight of the pump rods. To produce the downstroke, the passage between the steam-case and the bottom of the cylinder being closed, and that between the bottom of the cylinder and the condenser being opened, a vacuum would be created under the piston, and the steam, acting upon the top of it, would drive it to the bottom of the cylinder. The

[1] Muirhead's *Life of Watt*, 2nd ed., p. 90. Farey on the *Steam Engine*, p. 314.

piston-rod was required to work through a stuffing-box in the steam-case.

It was no longer possible, with this arrangement, to employ a stratum of water above the piston to keep the packing soft and tight. After trying different lubricants, Watt eventually fixed upon oil, or tallow, as the most suitable material for this purpose.

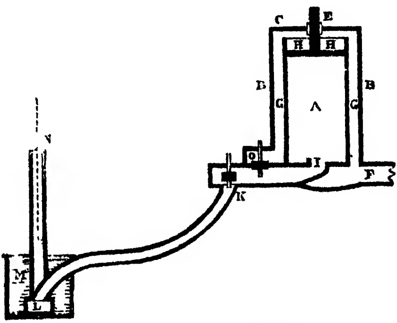

FIG. 28.—WATT'S STEAM-CASE.

A, the cylinder or steam vessel. B, outer cylinder or steam-case. C, cover, with hole for piston-rod. E. F, steam-pipe from boiler. G G, interstice between two cylinders. H H, piston. I, passage for admitting steam under the piston. K, valve in pipe to condenser, L. M, cistern, full of cold water. N, air-pump. O, equilibrium-valve.

With a view to keep the condenser as cold as possible, it was determined to place it in a tank kept constantly filled with cold water; and inasmuch as it was now impossible to employ steam to expel air from the condenser at each stroke of the engine, Watt arranged to dispense with the snifting-valve, and to use an air-

pump worked by the engine, to clear the condenser of both water and air at the same time.

Immediately after starting the idea of using a separate condenser, Watt proceeded to construct models to test the new plan by experiment. His first apparatus was designed to try the effect of condensing the steam and producing a vacuum in a

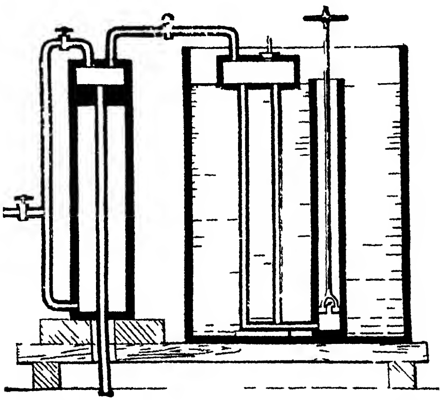

FIG. 29.—DIAGRAM OF WATT'S SEPARATE CONDENSER APPARATUS, 1765

vessel detached from the cylinder. The cylinder of his model (Fig. 29) consisted of a brass syringe one and three-quarter inches in diameter, and ten inches in length. Covers of tin-plate were applied at both ends. To save apparatus, the cylinder was inverted. The piston-rod was made hollow, and fitted with a valve at its lower end, to admit of the escape of the water

resulting from the steam condensed in first heating the cylinder. One pipe communicated between the boiler and both ends of the cylinder; another between the top of the cylinder and the condenser. The condenser consisted of two pipes of thin tin-plate, ten or twelve inches long, and about one-sixth of an inch in diameter, standing perpendicularly, and communicating at the top with a short horizontal pipe of large diameter, which had an aperture on its upper side shut by a valve opening upwards. These pipes were joined at the bottom to another perpendicular pipe about an inch in diameter, which served for the air and water pump; and both the condensing pipes and the air pump were placed in a small cistern filled with cold water.

"The steam-pipe was adjusted to a small boiler. When steam was produced, it was admitted into the cylinder, and soon issued through the perforation of the piston-rod, and at the valve of the condenser. When it was judged that the air was expelled, the steam-cock was shut, and the air-pump piston-rod was drawn up, which leaving the small pipes of the condenser in a state of vacuum, the steam entered them and was condensed. The piston of the cylinder immediately rose, and lifted a weight of about eighteen pounds, which was hung to the lower end of the piston-rod. The exhaustion-cock was shut, the steam was re-admitted into the cylinder, and the operation was

repeated; the quantity of steam consumed, and the weights it could raise, were observed; and, excepting the non-application of the steam case and external covering, the invention was complete, in so far as regarded the saving of steam and fuel. A large model, with an outer cylinder and wooden case, was immediately constructed, and the experiments made with it placed the advantage of the invention beyond the reach of doubt. It was found convenient afterwards to change the pipe-condenser for an empty vessel, generally of a cylindrical form, into which an injection played; and, in consequence of there being more water and air to extract, to enlarge the air-pump."[1]

The progress of Watt's invention was retarded for several years after his important discovery of the separate condenser, by untoward circumstances of various kinds. The new engine required a much nicer adjustment of parts than was necessary in Newcomen's engine. Even in constructing models, great difficulty was experienced in obtaining cylinders of a bore sufficiently accurate, and consequently in preventing the leakage of steam past the sides of the piston. The very fertility of Watt's genius operated to some extent as a hindrance; the idea of constructing a rotary engine lured him away for a time from his first invention.

[1] Muirhead's *Life of Watt*, 2nd ed. pp. 80-81.

Watt, moreover, was a poor man, and required to apply himself to other avocations than experimenting with steam engines, in order to earn a living for himself and family. Not being himself possessed of the necessary means to make trial of his engine on a large scale, and having besides incurred a debt of 1,000*l.* in the prosecution of his experiments, Watt, in 1767, entered into partnership with Dr. Roebuck, one of the founders of the ironworks which had recently been established at Carron, near Falkirk, for the manufacture of iron with mineral coal.[1] The terms of the partnership were, that Roebuck was to pay the above debt and all the expense of a patent and further experiments, in consideration of which two-thirds of the property in the invention was assigned to him.[2]

At length Watt had so far matured his engine, and got results of such a satisfactory character, as to decide him in securing the invention by a patent. In August, 1768, he proceeded to London with this object; and on the 5th of January, 1769, the memorable patent[3] for "*A new method of lessening the consumption of steam and fuel in fire engines,*" was obtained.

The building of a working engine near Dr. Roebuck's residence at Kinneil, some of the parts of which had been prepared several years before, was forthwith

[1] The first furnace at Carron was blown in on the 1st of January, 1760.

[2] Muirhead's *Life of Watt*, 2nd ed. p. 238.

[3] No. 913.

begun. It was set to work early in September; and though the results of its first trial were not very decisive, chiefly owing to the inequality of the cylinder arising from defective workmanship, it served to show that a very much less quantity of steam was required to work it, as compared with the common engine. Watt estimated the saving of steam at one-half, supposing that no further improvement could be effected on the engine.[1]

It had been doubtful, for some time, whether the state of Dr. Roebuck's affairs would admit of his providing the funds necessary to bring forward the invention, and Watt was anxious to secure the assistance of a partner better qualified for this purpose. Overtures had already been made to Mr. Boulton, of Soho, near Birmingham, with a view to inducing him to purchase a share in the enterprise, but no agreement had been arrived at. Now, when success seemed almost within reach, further progress was arrested by the increasing pecuniary embarrassment in which Dr. Roebuck was becoming involved. Neither of the partners could render assistance to the other. Watt was forced to abandon his steam-engine experiments, and betake himself to remunerative work, in order to obtain the necessaries of life. This was the darkest hour in the history of Watt's invention. The final insolvency of Dr. Roebuck, which followed soon after, proved a turning point for the better.

[1] Muirhead's *Life of Watt*, 2nd ed., p. 186.

CHAPTER XII.

WATT'S SINGLE-ACTING ENGINE FOR PUMPING WATER.

NONE of Roebuck's creditors regarded Watt's engine as worth a farthing. Among his debts was a sum of 630*l.* due to Boulton. An arrangement was therefore made whereby Boulton took up Roebuck's share in the engine patent, by releasing him from the above debt, and by engaging to pay a further sum of 1,000*l.* out of the first profits derived from the engine. A mutual discharge was executed between Roebuck and Watt in May, 1773;[1] and in the summer of the same year, the materials of the engine which had been built at Kinneil, were packed up and sent to Soho. About a year later, after completing his engagements in Scotland, Watt himself repaired to Soho and took up his residence there.

Experiments with the engine were resumed forthwith, and were attended with more decided success.

[1] Muirhead's *Life of Watt*, 2nd ed., pp. 237-8

Writing to his father in December, 1774, Watt informs him that the fire engine he had invented was now going, and answered much better than any other that had yet been made; he expected the invention would prove very beneficial to him.[1]

Encouraged by the favourable results which had been obtained, early in 1775, Boulton applied for a better cylinder, to Mr. John Wilkinson, an eminent iron-founder, who had introduced a new boring-machine which was an immense improvement on the old one.[2]

The prospects of the engine now began to brighten, but already six years of the period named in the patent had expired. So far the invention had been only a source of expense. A further outlay of capital was required before the manufacture of engines for the public could be commenced. It became evident that the unexpired term of the patent right was too contracted to afford a reasonable prospect of any adequate remuneration being obtained. Under these circumstances it was decided to apply to Parliament for a prolongation of the term, and in May, 1775, Watt had the pleasure of informing his father that an Act of

[1] Muirhead's *Life of Watt*, 2nd ed., p. 239. *Mechanical Inventions of James Watt*, Vol. II., p. 79.

[2] On the 27th of January, 1774, a patent was granted to John Wilkinson of Broseley, in the county of Salop, ironmaster, for casting and boring guns, cannon, &c. *Vide* No. 1063.

Parliament had been obtained, securing the monopoly of his invention for a term of twenty-five years.[1]

No time was now lost by Boulton and Watt in preparing for the manufacture of engines, and early in the following year two had been completed and set to work.

"We have now two large engines going," says Watt in a letter to Smeaton, dated April, 1776, "one about ten miles from Birmingham, the cylinder fifty inches diameter, intended to work a fourteen-and-a-quarter inch working barrel, to lift water from 100 yards deep; but the pit is only sunk to forty yards at present, they have a good deal of water, and the engine goes constantly. Their boiler is twelve-and-a-half feet diameter and is very bad, and the cylinder is not protected from the cold air. They burn only twenty-five hundredweight of the sweepings of an old coal-hill in twelve hours. I have never seen this engine go, so can tell you nothing more about it.

"The other engine is a thirty-eight inch cylinder, which blows an iron furnace at New Willey, in Shropshire; it acts immediately to compress the air in a blowing cylinder seventy-two inches diameter and seven feet stroke; as that cylinder is very rough and unevenly bored, I am uncertain what power it exerts, but it raises a column of water five-and-a-half feet high, in the air-chest of the water regulator, and goes fourteen strokes per minute, that is, a column of water seventy-two inches diameter, and five-and-a-half feet high. When I left it, there were several things unfinished; yet the quantity of fuel used seemed to be very moderate. Both these engines please even the workmen, who are all sufficiently captious. We are going on with several other large engines; one of a fifty-eight inch cylinder in Warwickshire, and our concern wears a business-like face.

[1] Muirhead's *Life of Watt*, 2nd ed., p. 242; *Mechanical Inventions of James Watt*, Vol. II., p. 89.

"Mr. Wilkinson has improved the art of boring cylinders; so that I promise upon a seventy-two inch cylinder being not further distant from absolute truth than the thickness of a thin sixpence in the worst part. I am labouring to improve the regulators; my scheme is to make them acute conical valves, shut by a weight, and opened by the force of the steam. They bid fair of success, and will be tried in a few days."[1]

The superiority of Watt's engine over Newcomen's, in power and economy of fuel, was soon demonstrated, and the success of the invention assured. People came daily to Soho to see the engines; the Cornish miners, who perhaps more than any others were interested in an economical engine, renewed their inquiries about it.[2] Orders from many quarters flowed in apace. "I have an application for an engine from a distiller at Bristol," says Boulton in a letter to Watt, dated 25th July, 1776, "to raise 15,000 ale gallons per hour 60 feet high; I have another for a coal-mine in Wales, another for a Mr. Langdale in Holborn, a distiller, and another for Mr. Liptrap, at Mile End, a distiller."[3] Towards the end of the same year, orders for engines began to arrive from Cornwall, and this county soon became the principal sphere for the application of the improved

[1] Farey on the *Steam Engine*, p. 320, note.

[2] *Mechanical Inventions of James Watt*, Vol. II., p. 98. As early as April, 1775, the Cornish mine-owners were becoming impatient to know the issue of Boulton and Watt's application to Parliament, and the terms they would propose in the event of an Act being obtained. [*Ibid.* p. 85.]

[3] *Mechanical Inventions of James Watt*, Vol. II., p. 101.

engines. So rapid was the adoption of Watt's engine in Cornwall, that in the short space of five or six years from their first introduction, all the engines in the county had been altered, with only one exception.[1]

In April, 1777, Smeaton went to see one of Watt's engines which had been erected at a distillery at Stratford-le-Bow, near London. He said "it was a pretty engine, but it appeared to him to be too complex."[2] Though Smeaton's own improvements on the fire engine were so signally eclipsed by the invention of Watt, much to his honour he acted towards Watt and his partner with the utmost candour and friendship, and even recommended a customer to them more than once [3]

The royalty charged by Boulton and Watt for the

[1] Muirhead's *Life of Watt*, 2nd ed., p. 265. In the colliery districts the atmospheric engines were much more slowly superseded—a few have even survived to the present day. At Whitehaven Collieries, in Cumberland, an atmospheric engine having a seventy inch cylinder is still employed in pumping. It was built in 1805, and is provided with a separate condenser. It works with a pressure of steam of 5 lbs. on the square inch above the atmosphere The writer is informed on reliable authority that several others are still in use at collieries in the Midland Counties.

[2] *Mechanical Inventions of James Watt*, Vol. II., p. 103. Smeaton was of opinion that Watt's engine would never be generally introduced on account of the difficulty of getting the parts of it made with the requisite precision. See Muirhead's *Life of Watt*, 2nd ed. pp. 249-50. Smiles's *Lives of the Engineers*, "Boulton and Watt," ed. 1874, p. 163.

[3] *Ibid.*, p. 111.

use of their patent engine was based upon the saving of fuel effected by it. They stipulated to receive the value of one-third of the fuel saved by each engine, when compared with a common one[1] burning the same kind of coal, to be paid annually or half-yearly, with an option of redemption at ten years' purchase.[2] To ascertain the dues chargeable, Watt invented the *engine counter*, by which the number of strokes made by an engine during any given time was accurately registered.

In the first engines built by Boulton and Watt, the steam-case was usually employed, inside of which an open-topped cylinder was placed.[3] This arrangement, however, being found very expensive, the method of covering the cylinder itself with a lid or cover (which had been used in some of the models), and conveying the steam to the lower end of the cylinder by a pipe, came to be generally adopted, and a less expensive method of employing the envelope of steam was used.[4] The only relic of the steam-case, which

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1 This did not include Smeaton's improved engines. [Farey on the *Steam Engine*, p 329, note.]

2 Muirhead's *Life of Watt*, 2nd ed., p. 290.

3 *Ibid.* pp. 90-1, 171. Price's *Mineralogia Cornubiensis*, p. 311. The engine erected by Boulton and Watt at Hawkesbury Colliery in Warwickshire, referred to in the letter from Watt to Smeaton above quoted, had an interior open-topped cylinder, as the writer was informed by the engineer who took it down. Price speaks of it as "justly supposed to be the most powerful engine in England" in 1778.

4 *Ibid.* p. 91. Farey on the *Steam Engine*, p. 329, note.

constituted an intermediate stage when the engine was passing from Newcomen's atmospheric engine into Watt's steam engine, is to be found in the *steam jacket*, still invariably used in Cornish pumping engines, as well as in other engines where economy of fuel is of the first importance.

Watt steadily declined to allow his separate condenser to be applied to engines of the old construction, on the plea that the invention would be placed under circumstances unfavourable to its full advantage being realized.[1]

The form of Watt's single-acting engine is shown in Fig. 30. To regulate the movements of the engine, three valves were employed—the *steam-valve*, placed in the pipe leading from the boiler to the top of the cylinder; the *equilibrium-valve*, in the pipe communicating between the top and the bottom of the cylinder; and the *exhaust-valve*, in the passage between the bottom of the cylinder and the condenser. The operation of the engine was as follows:—

The piston being at the top of the cylinder when the engine was at rest, as was the case in the atmospheric engine, all the valves were thrown open and steam was blown through the engine to expel air from the cylinder, pipes, and condenser, and fill every part with steam. The equilibrium-valve was then closed, the steam and

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[1] See letter from Watt to Smeaton in 1778, in Farey on the *Steam Engine*, p. 329, note.

exhaust valves being left open. The injection water being admitted into the condenser, the steam in the

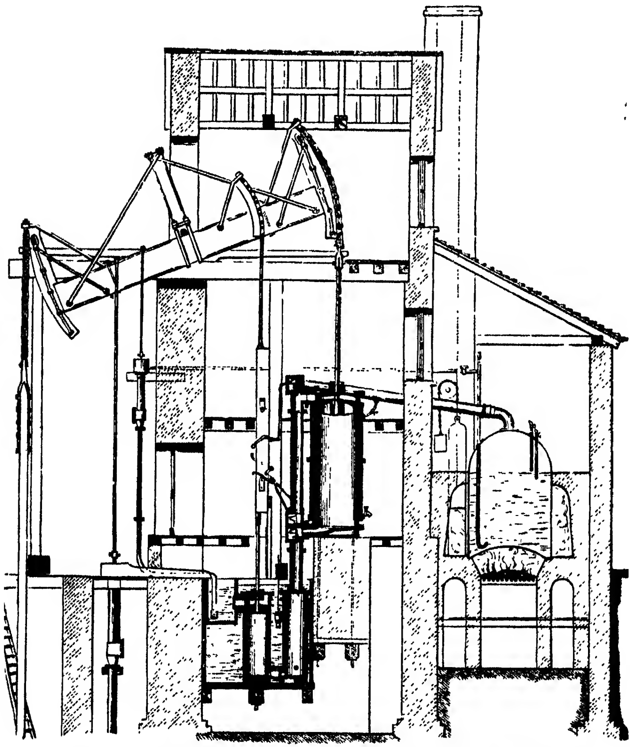

FIG. 30.—WATT'S SINGLE-ACTING ENGINE FOR DRAINING MINES.

cylinder was destroyed, and a vacuum produced under the piston, whereupon the steam from the boiler, pressing

upon its upper side, carried it to the bottom of the stroke. The steam and exhaust valves were then closed, and the equilibrium-valve was opened, thus allowing the steam to press equally on the upper and under sides of the piston; and the weight of the pump-rods, meeting with no resistance, carried the piston back to the top of the cylinder, the steam that was above it passing to its under side in the meanwhile. The equilibrium-valve was then closed, leaving the engine ready for another stroke, which ensued immediately upon the steam and exhaust valves being again opened. The steam was thus employed twice over, first above, and afterwards under, the piston, as is still the case in the Cornish pumping engine and other single-acting engines at the present day.

CHAPTER XIII.

WATT'S DOUBLE-ACTING ENGINE, OR ENGINE OF REVOLUTION, FOR DRIVING MILL-WORK OF ALL KINDS.

REFERENCE has already been made to the attempts on the part of Watt to produce continuous motion round an axis, by means of an engine of the steam-wheel class. In this he was unsuccessful. He was fully alive to the boundless field which existed for the application of an engine capable of producing a regular rotatory motion. It had occurred to him at an early period that the same object might be attained, though in a less direct manner, by means of the reciprocating engine, by employing two engines, acting upon two cranks fixed on the same axis, at an angle of 120 degrees to one another, and a weight placed upon the circumference of a fly-wheel at the same angle to each of the cranks, by which arrangement the motion might be rendered nearly equal, and only a very light fly-wheel would

be requisite.[1] So great, however, had been the demand for engines for raising water, that for some years Watt's attention had been wholly engrossed in this application of his invention.

In the year 1779, Mr. Matthew Wasbrough, of Bristol, took out a patent[2] for a steam or fire engine intended to produce continuous circular motion by ratchet-wheels, in a manner similar to what had been attempted by others before,[3] but with the addition of a *fly-wheel*, which was then employed for the first time in steam engines. Several of these engines were erected by Wasbrough; one was in his own workshops at Bristol, for turning lathes; another was set up at Mr. Taylor's saw-mill and block manufactory at Southampton; some others were made for grinding corn. One of these engines was erected by Wasbrough in Birmingham.[4] The frequent breakages and irregularities of this engine recalled to Watt's mind the method formerly conceived by him, for converting the reciprocating motion of an engine into a circular motion, and he proceeded to make a model which answered his expectations. Having neglected to take out a patent immediately, the application of the crank was communicated by a workman employed to make the model to some of

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[1] Muirhead's *Life of Watt*, 2nd ed , p. 275.

[2] No. 1213.

[3] For accounts of the methods employed by Mr. Dugald Clarke in 1769, and Mr. John Stewart in 1777, see Farey on the *Steam Engine*, p. 408.

[4] *Ibid.* p. 409.

the people connected with Wasbrough's engine, who, in 1780, removed the ratchet-wheels and substituted a crank in lieu of them, the fly-wheel being still retained

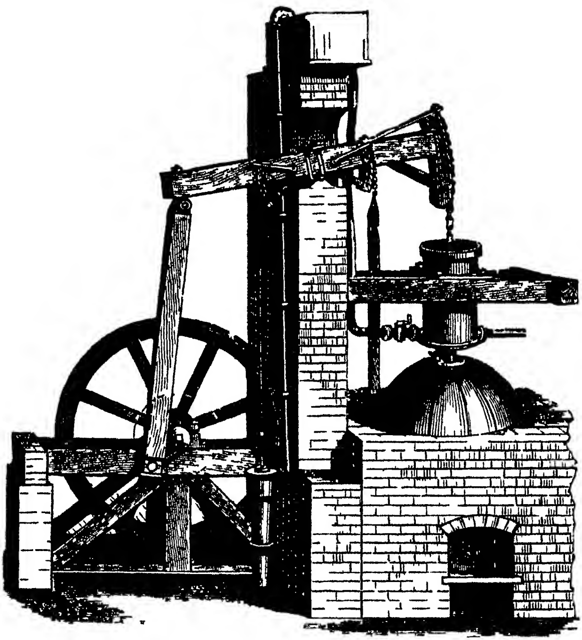

Fig. 31.—Atmospheric Engine with Crank and Fly Wheel, 1780

(Fig 31). Thus simplified, the engine answered very much better than anything which had been tried before Soon after, Watt had the mortification to

learn that the application of the crank to the steam engine had been patented.[1]

Finding himself shut out from using the crank, rather than contest the question at law, Watt set himself to devise other means of effecting the same end, and on the 25th October, 1781, he took out a patent[2] for five different methods of producing a continued rotative motion from a reciprocating engine, without the intervention of a crank. The only one of these which came into use was that known as the "sun and planet wheels,"[3] which was used by Boulton and Watt in their rotative engines, till the expiration of the patent for the crank.

The steam engine, however, was not yet sufficiently developed for producing a regular rotative motion. It was still only a *single-acting* machine. Cumbersome balances of one kind and another were required to equalise its force and carry on the motion during the return of the piston. By another stroke of genius Watt mastered this difficulty. He determined to apply the steam below, as well as above, the piston (a vacuum being at the same time produced on its opposite side), thus making the engine work equally in both

[1] Farey on the *Steam Engine*, p. 423; Muirhead's *Life of Watt*, 2nd ed., p. 276. The application of the crank to the steam engine was patented by Mr James Pickard of Birmingham, on Aug. 23rd, 1780. *Vide* No. 1263. [2] No. 1306.

[3] This was suggested by Murdock, but the idea had occurred to Watt himself during his earlier experiments.

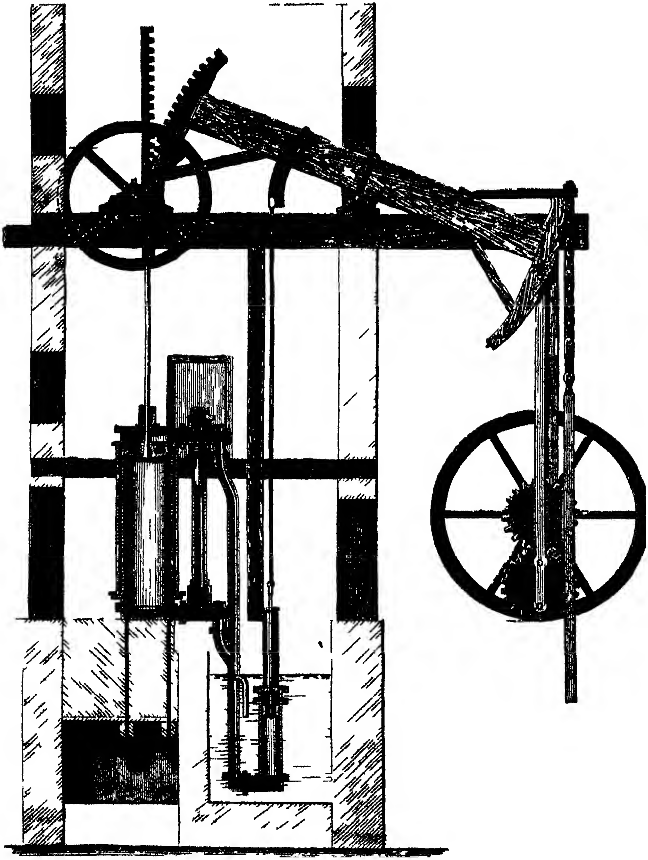

Fig 32 —Watt's Double acting Engine 1782

directions, or in other words, *double-acting*. This form of the engine he patented on the 12th of March, 1782.[1] This was the crowning improvement of the steam engine, and at once solved the difficulty of applying it successfully to produce a continuous rotative motion.

At first Watt employed a toothed rack and sector, as shown in Fig. 32, to enable the piston-rod to push

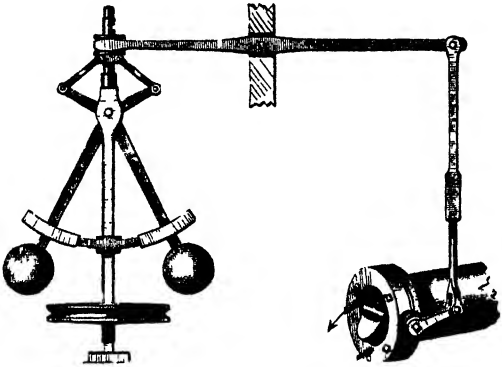

FIG. 33.—WATT'S GOVERNOR AND THROTTLE VALVE.

and pull equally, but this arrangement was superseded soon after by the beautiful invention of the *parallel motion*, which he patented on the 28th of April, 1784.[2]

From the first date of Newcomen's invention till now, the engine had been almost exclusively confined

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[1] No. 1321. Watt had thought of the double-acting principle some years previous to this date. [Muirhead's *Life of Watt*, 2nd ed. p. 281-2.]

[2] No. 1,432.

to raising water, but from this time it entered upon a career of world-wide utility. Among the first of its new applications was the driving of mills of all kinds

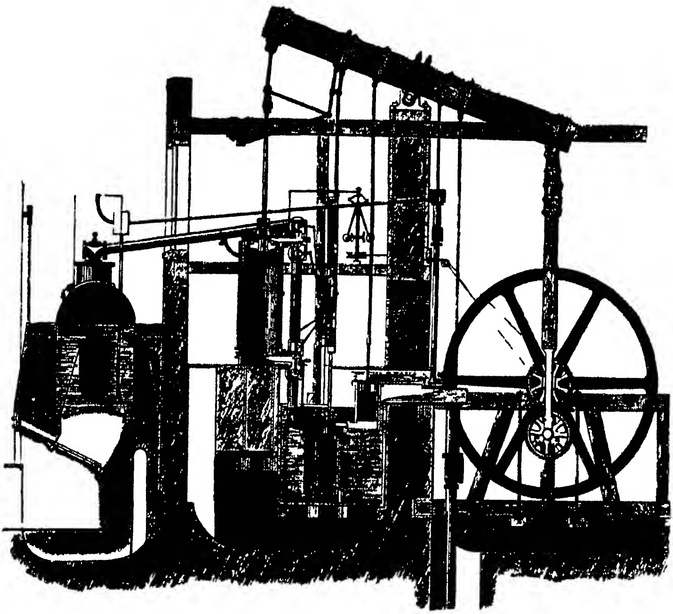

Fig. 34.—Albion Mills Engine, 1786.

To secure a regular and steady motion in the performance of mill engines, Watt invented the *throttle-valve*, to which he applied the apparatus known as the *governor* (Fig. 33), and made the engine self-regulating.[1]

[1] Muirhead's *Life of Watt*, 2nd ed., p. 291. A mechanism named the *lift tenter*, which bore some resemblance to the governor, had been

Of itself it now appropriated a larger or smaller quantity of steam, according to the load that was put upon it, without any intervention whatever on the part of the attendant. One of the earliest double-acting engines completed for sale, which combined all Watt's improvements, was one of those for the Albion Mills in London. It was set to work in 1786.[1] This engine is shown in Fig. 34.

In the double-acting engine four valves were required —two steam-valves, and two exhaust-valves. The equilibrium-valve was not employed in this form of engine; after pressing the piston down or up, as the case might be, the steam passed directly from the cylinder to the condenser.

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previously used for regulating the velocity of millstones. See Stuart's *Anecdotes of Steam Engines*, Vol. II., pp. 359-61.

[1] Muirhead's *Life of Watt*, 2nd ed., p. 282.

CHAPTER XIV.

PROJECTS FOR APPLYING THE STEAM ENGINE TO PROPEL CARRIAGES AND BOATS.

THE invention of the double-acting engine by Watt, in 1782, and the facility with which the machine could now be applied to produce continuous rotatory motion, was a great stride towards the solution of the problems of steam locomotion and steam navigation. These applications of the steam engine were among the projects which suggested themselves to the fertile imagination of Papin. He had foreseen the difficulty in the former case, on account of the roughness and inequalities of common roads, but thought that the level surface of water presented a fine field for the application of *voitures par eau.*[1] His strenuous but

[1] *Vie de Papin*, par L. de la Saussaye et A. Pean, Vol. I., p. 208. It seems that Papin had constructed a small model locomotive engine in 1698, though the fact appears to have been generally overlooked. In a letter to Leibnitz, dated 25th July in this year, he refers to it as follows :—"J'ay fait un petit modèle d'un chariot qui avance par cette force (*i.e.* steam) : et il fait, dans mon poêle, l'effect que j'en avois attendu," &c.

unavailing efforts to get the subject taken up have been already referred to. The crude mechanism which he proposed to employ presented little prospect of success.

In the year 1736, shortly after the expiration of the patent for Newcomen's engine, Jonathan Hulls obtained a patent [1] for the application of the atmospheric engine to actuate a paddle-boat for towing vessels into and out of harbours, &c., and in the following year he published an account of his project, together with a description of the machinery he proposed to employ [2]; but it does not appear that any attempts were made to put the scheme into practice, and there is little doubt that the same obstacles which baffled the early attempts to derive a rotative movement from the atmospheric engine on shore, would have resulted in a similar failure in the case of the paddle-boat.

An attempt to achieve locomotion by steam, which was attended with some success, was made by Cugnot, at Paris, about 1769.[3] The steam engine being at this

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[1] No. 556.

[2] *A Description and Draught of a New-invented Machine for carrying vessels or ships out of, or into, any Harbour, Port, or River, against Wind and Tide, on in a Calm*, by Jonathan Hulls, London, 1737. Reprinted at London by George E. Eyre and William Spottiswoode in 1858, and by E. and F. N. Spon in 1873.

[3] *Locomotive Engineering*, by Zerah Colburn, 1871, pp. 9-10. *A History of the growth of the Steam Engine*, by Robert H. Thurston, A.M., C.E., 2nd ed., London, 1879, pp., 151-2. Smiles's *Lives of the Engineers*—"George and Robert Stephenson," ed. 1874, pp. 64-5.

period still a single-acting machine, in order to produce a continuous rotative movement, Cugnot employed two open-topped high-pressure steam cylinders, the piston-rods working upon the same axis. His steam carriage was, however, of no practical utility, and was soon laid aside.

The history of steam locomotion and steam navigation really commences subsequently to the invention of Watt's double-acting engine in 1782. There was from this time no difficulty in applying the engine to produce continuous rotatory motion—the one desideratum for the successful accomplishment of both projects. With the latter Watt did not concern himself, but the application of the steam engine to propel wheel-carriages was included in his patent of April 28th, 1784, as appears from the following passage :—

"My seventh new improvement is upon steam engines which are applied to give motion to wheel carriages for removing persons, or goods, or other matters, from place to place, in which cases the engines themselves must be portable. Therefore, for the sake of lightness, I make the outside of the boiler of wood, or of thin metal, strongly secured by hoops, or otherwise, to prevent it from bursting by the strength of the steam. . . . The form of the boiler is not very essential, but a cylindric or globular form is best calculated to give strength. I use cylindrical steam vessels with pistons, as usual in other steam-engines, and I employ the elastic force of steam to give motion to these pistons ; and after it has performed its office I discharge it into the atmosphere by a proper regulating valve, or I discharge it into a condensing vessel made air-tight and formed of thin plates or pipes of metal, having their outsides

exposed to the wind, or to an artificial current of air produced by a pair of bellows, or by some similar machine wrought by the engine or by the motion of the carriage. . . . In some cases I apply to this use engines with two cylinders, which act alternately; and in other cases I apply those engines of my invention which act forcibly both in the ascent and descent of their pistons. . . . I communicate the power of these engines to the axis or axletree of one or more of the wheels of the carriage, or to another axis connected with the axletree of the carriage by means of toothed wheels. . . . To drive a carriage containing two persons will require an engine with a cylinder seven inches in diameter, making sixty strokes per minute of one foot long each, and so constructed as to act both in the ascent and descent of the piston; and the elastic force of the steam in the boiler must occasionally be equal to the supporting a pillar of mercury thirty inches high."[1]

Watt appears to have included this application of the steam engine in his patent, not so much with any intention of taking up the subject, as in order to prevent himself from being anticipated by others. He had no faith in its success. The case was different, however, with William Murdock, the representative of Boulton and Watt, and the superintendent of their pumping engines in Cornwall. Murdock was a highly ingenious Scotch mechanic. He was born in 1754, at Bellow Mill, near Old Cumnock, in Ayrshire. He was the inventor of the oscillating cylinder, and the slide-valve, besides many other ingenious devices.[2] In 1784

[1] See his specification, which is also printed in the *Mechanical Inventions of James Watt*, Vol. III., p. 110.

[2] Muirhead's *Life of Watt*, 2nd ed., pp. 412-416, 439. Smiles's *Lives of the Engineers*—"Boulton and Watt," ed. 1874, p. 344. Murdock

Murdock made a working model of a high pressure locomotive engine (Fig. 35), which performed well. In that year it was repeatedly seen by his friends, and various persons in the neighbourhood, drawing a small model waggon round a room in his house at Redruth.[1] Murdock was eager to engage in the manufacture of steam carriages for sale, under a licence from his employers, or

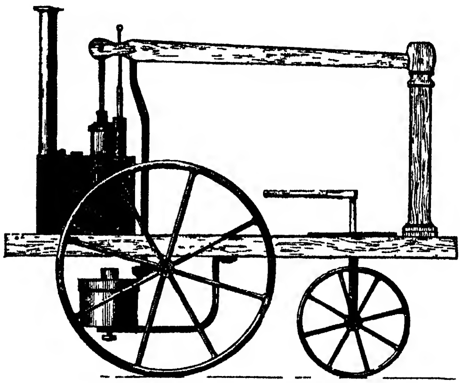

FIG. 35.—MURDOCK'S MODEL OF A LOCOMOTIVE ENGINE, 1784.

in partnership with them.[2] He continued to entertain the idea for some time, but Watt discountenanced the

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was the first to employ coal-gas for illuminating purposes. His house at Redruth was lighted by this means in 1792. He afterwards applied it at Soho, and many other large manufactories. A biographical notice of Murdock, by Mr. Buckle of Soho, was published in the *Proceedings of the Institute of Mechanical Engineers*, October, 1850.

[1] Muirhead's *Life of Watt*, 2nd ed., p. 438.

[2] *Ibid.* p. 445.

scheme. The following extract from a letter from Watt to Boulton, dated September 12th, 1786, shows his feeling in the matter:—

"I am extremely sorry that W[illiam] M[urdock] still busies himself with the steam-carriage. In one of my specifications I have secured it as well as words could do it according to my ideas of it; and if to that you add Symington's and Sadler's patents, it can scarcely be patentable, even if free of the general specification in the Act of Parliament; for even granting that what I have done cannot secure it, yet it can act as prior invention against anybody else, and if it cannot be secured by patent, to what purpose should anybody labour at it? I have still the same opinions concerning it that I had; but to prevent as much as possible more fruitless argument about it, I have one of some size under hand, and am resolved to try if God will work a miracle in favour of these carriages. I shall in some future letter send you the words of my specification on that subject. In the meantime I wish W[illiam] could be brought to do as we do, to mind the business in hand, and let such as Symington and Sadler throw away their time and money hunting shadows."[1]

Watt's remonstrances seem to have had the desired effect of bringing Murdock to abandon the steam carriage experiments and apply himself to his business,[2]

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[1] Muirhead's *Life of Watt*, 2nd ed., p. 445. *Mechanical Inventions of James Watt*, Vol. II., pp. 210-211.

[2] *Ibid.* Murdock's attention was directed to the subject of the locomotive engine during a period of two years (1784-6). There are good grounds for believing that he was not occupied with his model during the whole of this time, but constructed at least one large engine. In a letter from Trevithick to Mr. Davies Giddy, dated 1st October, 1803, the following passage occurs:—

"I have desired Captain A. Vivian to wait on you to give you every information respecting Murdock's carriage, whether *the large one* at

and from this time nothing more is heard of the locomotive engine during the continuance of Watt's patent.

Of the practicability of steam navigation Watt had a scarcely less unfavourable opinion. Into the subject of the unsuccessful attempts to introduce steam vessels made in France and America, towards the end of the eighteenth century, it is not necessary to enter, as they led to no result. Mention, however, must be made of the experiments of Mr. Patrick Miller, of Dalswinton, in Scotland, which, apparently only wanted the countenance of Watt to have afforded a solution of the problem of steam navigation. In 1787 Mr. Miller published a description, with engravings, of a triple vessel, propelled by paddle-wheels, turned by means of cranks, intended to be worked by men. "I have also reason to believe," he remarks, "that the power of the steam engine may be applied to work the wheels, so as to give them a quicker motion, and consequently to increase that of the ship." In the following year (1788) Mr. Miller employed Mr. William Symington,[1] of Wanlockhead,

Mr. Budge's foundry was to be a condensing engine or not."—*Life of Richard Trevithick*, by F. Trevithick, C.E., London, 1872, Vol. II., p. 126.—See also *The Self-Aid Cyclopædia*, by Robert Scott Burn, London, N.D.; p. 110 of the *History of the Steam Engine*.

This was probably the "steam carriage" referred to by Watt in a letter to Boulton, dated September 23rd, 1786. [*Mechanical Inventions of James Watt*, Vol. II. p. 211.]

[1] Symington took out a patent for a steam engine in 1785, and constructed a steam carriage about the same date. It is figured in

in Dumfriesshire, along with Mr. James Taylor, to superintend the construction of a small steam engine in a pleasure boat on Dalswinton Loch. "Nothing," it is stated, "could be more gratifying or complete than the success of this first trial, and while for several weeks it continued to delight Miller and his numerous visitors, it afforded him the fullest assurance of the justness of his own anticipation, and the possibility of applying to the propulsion of his vessels the unlimitable power of steam." In the course of the year 1789 preparations were made for an experiment upon a larger scale. Symington was again employed by Miller to superintend the construction of the machinery, which was made at Carron ironworks. The trials of the new apparatus were made in the month of December, in one of Miller's boats, on the Forth and Clyde canal. A speed of seven miles an hour was attained, and the practicability of the scheme was established.[1]

That Miller should have abandoned his steamboat

Self-Aid Cyclopædia, by Robert Scott Burn, London, N.D.; *History of the Steam Engine*, p. 111.

The engine made by Symington for the boat on Dalswinton Loch had two brass cylinders four inches in diameter. It is stated to be preserved in the Museum of the Andersonian University at Glasgow. [*Railways, Steamers, and Telegraphs*, by George Dodd, London and Edinburgh, 1868, p. 119.]

[1] Muirhead's *Life of Watt*, 2nd ed., pp. 424 5. *Historical account of the Steam Engine and its application in propelling vessels*, by James Cleland, Glasgow, 1825, p. 48. Stuart's *Anecdotes of Steam Engines*, Vol. II., p. 393. Woodcroft on "Steam Navigation," in *Transactions of the Society of Arts*, 1846-7.

experiments, immediately after such a promising beginning, has frequently been regarded as unaccountable. The explanation of the matter is very probably to be found in the attitude assumed by Boulton and Watt. Mr. Cullen of Edinburgh (afterwards Lord Cullen) seems to have taken a lively interest in Miller's experiments. He wrote an account of them in the Edinburgh newspapers of the day, and appears to have addressed an application, on the part of Miller, to Boulton and Watt, with a view to engaging them to connect themselves with Miller's undertaking.

The following reply from Watt to Mr. Cullen, dated April 24th, 1790, throws some interesting light upon the subject:—

"Dear Sir,—We have heard of Mr. Miller's ingenious experiments on double ships from Sir John Dalrymple, and also some vague accounts of the experiments with the steam engine, from which we could gather nothing conclusive, except that the vessel did move with a considerable velocity.

"From what we heard of Mr. Symington's engines, we are disposed to consider them as attempts to evade our exclusive privilege; but as we thought them so defective in mechanical contrivance as not to be likely to do us immediate injury, we thought it best to leave them to be judged by Dame Nature first, before we brought them into an earthly court.

"We are much obliged to Mr. Miller for his favourable opinion of us and of our engines, which we hope experience will more and more justify. We are also fully sensible of his kind attentions in offering to associate us in his scheme; but the time of life we have both arrived at, and the multiplicity of business we are already engaged in, must plead our excuse from entering

into any new concern whatsoever as partners,—but as engineers and engine-makers, we are ready to serve him to the best of our abilities, at our customary prices of rotative engines, and to assist in anything we can to bring the scheme to perfection.

"We conceive there may be considerable difficulty in making a steam engine to work regularly in the open sea, on account of the undulatory motion of the vessel affecting the engine by the *vis inertiæ* of the matter; however, this we should endeavour to obviate as far as we can.

"It may not be improper to mention that Earl Stanhope has lately taken a patent for moving vessels by steam, but we believe not by wheels. His lordship has also applied to us for engines, but we believe we are not likely to agree with him, as he lays too much stress upon his own ingenuity.

"We cannot conclude without observing that, were we disposed to enter into any new concern, there is no person we should prefer to Mr. Miller as an associate, being fully apprised of his worth and honour, and admirers of the ingenuity and industry with which he has pursued this scheme.

"Permit me now, sir, to return you my thanks for your obliging attention to me, and the trouble you have taken in this affair, and to ask the favour of you to present Boulton and Watt's respectful compliments to Mr. Miller.—Dear Sir, your obliged humble servant, JAMES WATT.

Robert Cullen, Esq., Edinburgh."[1]

The manufacture of stationary condensing engines afforded an ample field for all the energies of Boulton and Watt, without the necessity for their entering upon any new and untried courses. Their patent privileges, so long as they remained in force, stood in the way of others disposed to do so.

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[1] *Memorials of James Watt*, by George Williamson, Esq., Printed for the Watt Club, 1856, pp. 219, 220.

CHAPTER XV.

CONCLUDING REMARKS REGARDING WATT'S ENGINE. RIVAL ENGINES.

To the last Watt continued to employ steam of a pressure similar to that which had been used in Newcomen's engines, that is, not more than one or two pounds above the pressure of the atmosphere. Thus the steam engine in the hands of Watt was the *perfection of the vacuum engine,* which, as we have seen, a long line of inventors had been striving to produce. The steam was now used with the greatest economy compatible with the employment of low-pressure steam; the vacuum was produced under the most favourable conditions. But in bringing the engine into the form which it had now arrived at, Watt had at the same time mastered the difficulties in the way of employing steam of a higher pressure. Nothing now prevented its use above, as well as below, the piston; a stronger boiler only was necessary.

That Watt did not employ steam of a higher pressure was not the result of ignorance, as has sometimes been supposed. His objection to it appears to have been founded chiefly on the danger which he feared would attend its use. Yet he took the precaution to include the non-condensing form of engine in his patent of 1769. "In cases where cold water cannot be had in plenty," he says, "the engines may be wrought by the force of steam only, by discharging the steam into the open air after it has done its office."

A little later we find Boulton urging Watt to employ steam of a higher pressure, on account of its superior economy. In a letter to Watt, dated July 25th, 1776, he writes as follows:—

"I did not sleep last night, my mind being absorbed in STEAM; and thus I reasoned in my waking dreams:—

Power of one atmosphere costs	1012° 40	of heat or of money, which amounts to	1012	per atmosphere.
Ditto of two .	1052 23	,,	526	,,
Ditto of three	1075 15	,,	358	,,
Ditto of four	1090	,,	272	,,

Hence the price of the power of one atmosphere is reduced from 1,012 pence, or shillings, to 272 pence, or shillings, which is almost four times better. Then as to boilers and steam-pipes, let them be as strong as cannon; but as the fire will not be applied so advantageously through thick metal, let it be applied in copper spheres within the water, and then four or five atmospheres will not compress such forms. The great boiler may be framed with scantlings of cast-iron, well screwed together with wrought-iron plates

half-inch thick, well-fitted and screwed within; and then, the greater the elastic force of the steam, the closer they will be pressed, as the lid of a digester is. As to the piston, it may be laid with asbestos cloth, if oakum will not stand the heat, and by this means the present construction of the engine will do. But certainly it's a desirable thing to invent an engine to work with the expansive and contractive power of steam, as I am clear the principle is sound."[1]

Watt appears to have been unmoved by the appeals of his partner to use strong steam, preferring security from accident to increased profits, but the value of working expansively had been well known to him as early as 1769, as appears from one of his letters to Dr. Small.[2] About 1776 the engine at Soho was adapted to work expansively, and an attempt was made by Boulton and Watt to apply the principle generally, but they found it necessary to desist, owing to insufficient skill on the part of the enginemen. The expansive principle, however, was included in Watt's patent of 1782 (Fig. 36).

Among the many improvements effected by Watt, with a view to promote economy of steam and fuel in his engines, was the introduction of new forms of valves and boilers.

The valves consisted of circular brass plates made conical at their edges, and ground to their seats with

[1] *Mechanical Inventions of James Watt*, Vol. II., pp. 101-2.

[2] Farey on the *Steam Engine*, p. 339.

[3] Smiles's *Lives of the Engineers*—"Boulton and Watt," ed. 1874, p. 172.

emery, so as to make them a perfectly tight fit (Fig. 37). They were opened when necessary by means of weighted levers, and when shut were kept close by the pressure of the steam [1]

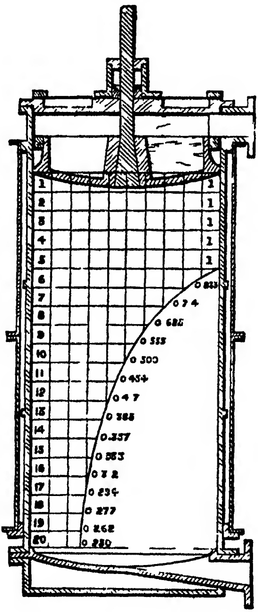

FIG 36 —WATT'S DIAGRAM, SHOWING EXPANSION OF STEAM, 1782

The boilers employed by Savery and Newcomen were of a circular form, the hot air being carried round in the form of a spiral, on its way from the

[1] Farey on the *Steam Engine*, p 373-4.

furnace to the chimney. Watt elongated his boilers into the form known as the *waggon boiler*, the hot air being carried round its sides as before. By this alteration a larger proportionate surface was exposed to the action of the heat, and a greater economy of fuel was obtained, together with increased evaporative power.

Watt appears at no time to have followed Newcomen's plan of placing the cylinder immediately over

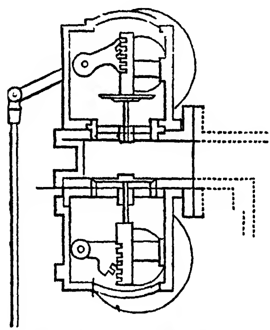

FIG. 37.—FORM OF VALVES EMPLOYED BY WATT.

the boiler, but always upon a separate foundation alongside of it.

The great success attending the introduction of Watt's engines led to several attempts to construct engines of different forms, with a view to the evasion of his patent. Conspicuous among these were the *compound*, or double-cylinder engine, of Jonathan

Hornblower, and the *direct-acting*, or inverted cylinder engine, of William Bull.[1] Both Hornblower and Bull were Cornish engineers. They were well acquainted with the construction of Watt's engine; the latter had been employed as a stoker, and afterwards as an engineman, by Boulton and Watt.[2]

The form of Hornblower's engine is shown in Fig. 38. It was designed to utilize the expansion of the steam from the smaller into the larger cylinder. Being a single-acting engine, when it was at rest the pistons remained at the top of their respective cylinders. The action of the engine was as follows: all the valves having been opened, steam was blown through to expel the air from the cylinders, pipes, and condenser, and fill them with steam. The equilibrium-valves of both cylinders having been closed, and the steam-valves and exhaust-valve being open, on the injection water

[1] A curious and little-known form of two-cylinder engine was invented by Adam Heslop, and patented in 1790. The cylinders were at opposite ends of the beam, and were known as the hot and cold cylinders respectively. A number of Heslop's engines were erected at collieries in Cumberland, both for winding and pumping purposes, but they appear to have been unknown beyond the limits of this county. For descriptions of these engines see *Transactions of the Cumberland and Westmorland Antiquarian and Archæological Society*, Part II. Vol. III., for 1877-8, p. 292.—*The Heslop Engine*, &c., by H. G. Fletcher, read at the meeting of the Institution of Mechanical Engineers in London, 17th Jan., 1879.—*Engineering* for Jan. 31st, 1879.

[2] Muirhead's *Life of Watt*, 2nd ed., p. 391.

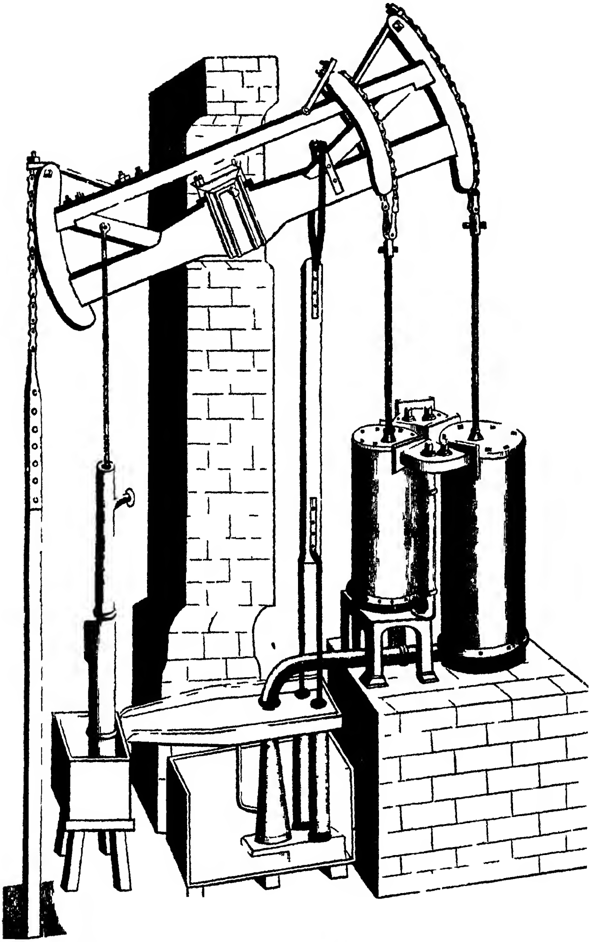

Fig. 88.—Hornblower's Single acting Compound Engine. 1781.

being thrown into the condenser a vacuum was produced under the piston of the large cylinder, which, in consequence, was pressed down by the steam flowing into the top of the large cylinder through the pipe communicating with the bottom of the small cylinder, the steam from the boiler meanwhile following the little piston downwards, and pressing upon it with increasing effect as the expansion of the steam reduced the pressure beneath it. On the pistons arriving at the bottom of their strokes, the steam and exhaust valves were closed, and the equilibrium valves of both cylinders were opened, whereupon the weight of the pump-rods carried the pistons back to the top of the cylinders, the steam which had previously been above each piston flowing through the communicating pipe and filling the cylinders below the pistons. The engine was then ready for another stroke, which followed immediately upon the equilibrium-valves being closed, and the steam and exhaust valves being again opened.

Hornblower obtained a patent [1] for his engine, in July, 1781. He became associated with a Mr. Winwood, of Bristol.[2] His first engine was erected at Radstock, near Bristol, in 1782.[3] The cylinders were nineteen

[1] No. 1298. He is described as "of Penryn, in the county of Cornwall, plumber and brazier."

[2] Pole on the *Cornish Engine*, p. 38, note *An Address to the Mining Interest of Cornwall*, by Thomas Wilson, 1793, p. 4.

[3] Muirhead's *Life of Watt*, 2nd ed., p. 388. *Mechanical Inventions of James Watt*, Vol. II., pp. 152, 161.

inches and twenty-four inches in diameter, and the strokes six feet and eight feet respectively.[1] This engine does not appear to have been a success. Watt, however, proceeded to Bristol, and cautioned Hornblower's employers, and the public, against using this form of engine, as being a direct infringement of his patent.[2] Hornblower's next engine was not erected till 1790. It was at the Tin Croft mine, near Redruth.[3] This engine acted well, and in 1792 Hornblower applied to Parliament for an extension of his patent, but the application was refused through the opposition of Boulton and Watt.[4]

The form of Bull's engine is shown in Fig. 39. It acted in a precisely similar manner to Watt's single-acting engine, only that the inversion of the cylinder caused the operations to be reversed to some extent. The steam from the boiler was admitted *under* the piston, while the vacuum was produced *above* it. The weight of the pump-rods brought the piston back to the bottom of the cylinder, the steam in the meanwhile

[1] Farey on the *Steam Engine*, p. 388.

[2] Smiles's *Lives of the Engineers*—"Boulton and Watt," ed. 1874, pp. 256 7. Both Hornblower and Bull employed the separate condenser in their engines.

[3] Farey on the *Steam Engine*, p. 387. Pole on the *Cornish Engine*, p. 37. *An Address to the Mining Interest of Cornwall*, by Thomas Wilson, 1793.

[4] Pole on the *Cornish Engine*, p. 38. Farey on the *Steam Engine*, p. 389.

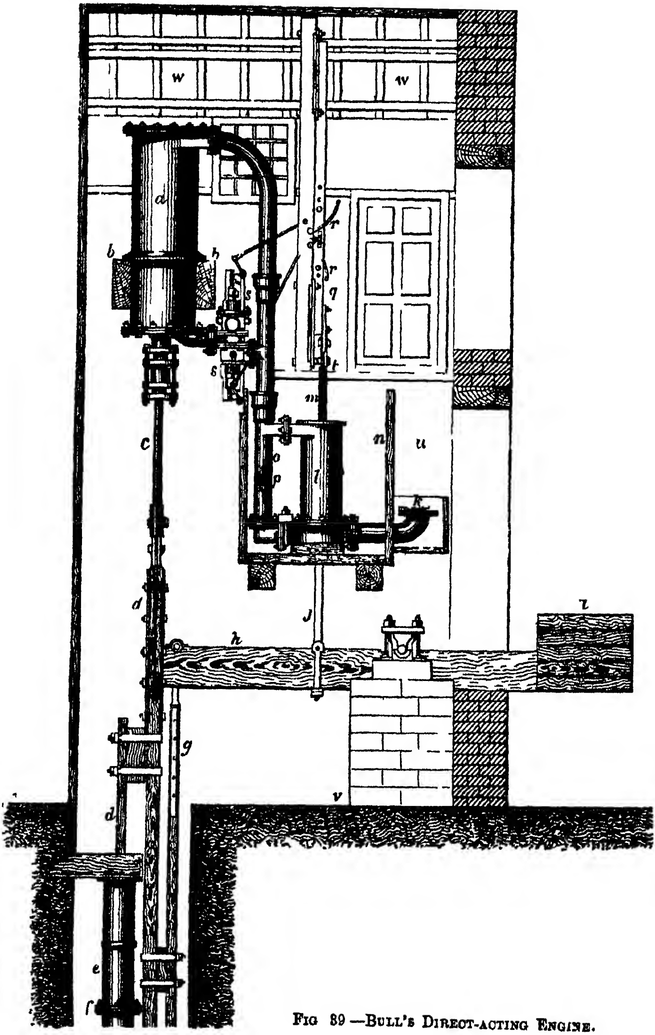

FIG 89.—BULL'S DIRECT-ACTING ENGINE.

flowing through the equilibrium-valve, and filling the cylinder above the piston.

In 1793 Boulton and Watt instituted legal proceedings against Bull, founded on an engine he had erected at Oatfield mine. The verdict was for the plaintiffs, subject to the opinion of the Court as to the validity of their patent. The special case was tried in 1795, but the opinions of the judges were equally divided, and no decision was given.

In the meantime Hornblower had continued to erect his engines, and his opposition had become so formidable to Boulton and Watt as to compel them to bring an action against him. The cause was tried on the 16th of December, 1796, when a verdict was again given for the plaintiffs, subject, as in Bull's case, to the opinion of the judges. The final hearing came on in January, 1799, close upon the expiration of Watt's patent, when the validity of the patent was established by the unanimous opinion of the four judges. The great importance of the case to Boulton and Watt may be inferred from the fact that they are stated to have recovered 40,000*l.* for arrears of patent dues.[1]

The partnership of Boulton and Watt had proved a remarkably happy one. It is not too much to say

[1] Pole on the *Cornish Engine*, pp. 36-39; Muirhead's *Life of James Watt*, 2nd ed., pp. 389-403; *Mechanical Inventions of James Watt*, Vol. III., pp. 164-292.

that the commercial success which attended the introduction of Watt's invention was in a large measure due to the favourable conditions under which it was brought out. The wealth and influence, the energy and tact, of Boulton, were invaluable complements to the inventive genius of Watt. On the expiration of the term of twenty-five years, during which they had held the monopoly of the invention, the partnership was dissolved, Boulton and Watt retiring from the business and handing it over to their sons.

The encomiums which have been pronounced upon Watt and his invention, are too numerous and well known to require more than a passing allusion. Sir Walter Scott, Sir Humphry Davy, Lord Brougham, Lord Jeffrey, and others of the most distinguished of his contemporaries in literature and science, have celebrated the praises of the illustrious inventor.

The account of the steam engine, however, given by Dr. Erasmus Darwin, in his *Botanic Garden*, is possessed of considerable historic interest, both from the date at which it was written (1789), and also from the fact of its having been the subject of correspondence between Watt and his friend Darwin, who had applied to him for materials for his poem.[1] Dr. Darwin reviews the

[1] "I intend to publish the *Economy of Vegetation* in the spring:" says Darwin, in a letter to Watt dated November 20th, 1789,—"now in this work I shall in a note mention something about steam engines. . . . . If you will at a leisure hour tell me what the world may

invention of the engine, recounts the uses to which it was put at the time when he wrote, and gives a prophetic forecast of the future that lay before it, in the following lines:—

"Nymphs! you erewhile on simmering caldrons play'd,
And call'd delighted SAVERY to your aid;
Bade round the youth explosive STEAM aspire
In gathering clouds, and wing'd the wave with fire;
Bade with cold streams the quick expansion stop,
And sunk the immense of vapour to a drop.
Press'd by the ponderous air, the piston falls
Resistless, sliding through its iron walls;
Quick moves the balanced beam, of giant birth,
Wields his large limbs, and nodding shakes the earth.

"The giant-power from earth's remotest caves
Lifts with strong arm her dark reluctant waves;
Each caverned rock and hidden den explores,
Drags her dark coals, and digs her shining ores.
Next, in close cells of ribbed oak confined,
Gale after gale, He crowds the struggling wind;

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know about your *improvements* of the steam engine, or anything about your experiments, or calculated facts about the power of your engines, or any other *ingenious stuff* for a note, I shall with pleasure insert it, *either with or without your name,*" &c.

In his reply, dated November 24th, 1789, Watt says to Darwin:—"I know not how steam engines come among the plants; I cannot find them in the *Systema Naturæ*, by which I should conclude that they are neither plants, animals, nor fossils, otherwise they could not have escaped the notice of Linnæus. However, if they belong to *your* system, no matter about the Swede; and your kind attention to us will certainly make me furnish you with all the necessary materials for poetic readers," &c.—*Mechanical Inventions of James Watt,* Vol. II., pp. 230, 232.

The imprison'd storms through brazen nostrils roar,
Fan the white flame, and fuse the sparkling ore.
Here high in air the rising stream He pours
To clay-built cisterns, or to lead-lined towers;
Fresh through a thousand pipes the wave distils,
And thirsty cities drink the exuberant rills.
There the vast millstone with inebriate whirl
On trembling floors His forceful fingers twirl,
Whose flinty teeth the golden harvests grind,
Feast without blood! and nourish human-kind.

"Now his hard hands on Mona's rifted crest,
Bosom'd in rock, her azure ores arrest;[1]
With iron lips His rapid rollers seize
The lengthening bars, in thin expansion squeeze;
Descending screws with ponderous fly-wheels wound
The tawny plates, the new medallions round;
Hard dies of steel the cupreous circles cramp,
And with quick fall His massy hammers stamp.
The harp, the lily, and the lion join,
And GEORGE and BRITAIN guard the sterling coin.

"Soon shall thy arm, UNCONQUER'D STEAM! afar
Drag the slow barge, or drive the rapid car;
Or on wide-waving wings expanded bear
The flying-chariot through the fields of air.
Fair crews triumphant, leaning from above,
Shall wave their fluttering kerchiefs as they move;
Or warrior-bands alarm the gaping crowd,
And armies shrink beneath the shadowy cloud."

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[1] For some years before the publication of Dr. Darwin's poem the copper mines of Anglesea had been exceedingly productive. About 1784 they yielded 3,000 tons of copper annually.

CHAPTER XVI.

THE STEAM ENGINE AFTER THE EXPIRATION OF WATT'S PATENT—TREVITHICK'S HIGH-PRESSURE ENGINE AND STEAM CARRIAGE.

NOTWITHSTANDING the immense superiority of Watt's low-pressure engine over Newcomen's, alike as regards power, economy, and utility, the steam engine as yet was only in the infancy of its applications. On the expiration of Watt's patent, in the year 1800, it entered upon a new career.[1] The era of high-pressure

[1] By the employment of steam of a higher pressure, and working expansively, aided by improvements in the boilers and pumping arrangements, the Cornish engineers succeeded in enormously increasing the economy of their pumping engines after the withdrawal of Boulton and Watt's agents from the county on the expiration of the patent. The following is a brief account of the history of the Cornish pumping engine:—

At the commencement of the introduction of Watt's engines into Cornwall, in 1778, a committee was appointed to ascertain the performance of the atmospheric engines, then at work in the county, in order to fix a basis for the dues payable to Boulton and Watt for their

steam, of steam locomotion and steam navigation, properly commences from this date. Nothing new was introduced in the mechanism of the engine; in its main features it has remained to the present day very much in the form given to it by Watt. The vacuum,

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improved engines. It was then agreed upon that the average duty of the atmospheric engines was 7,037,800 lbs. raised one foot high by the consumption of a bushel (94 lbs) of coal. [Pole on the *Cornish Engine*, pp. 24-5]. Boulton and Watt's low-pressure engines performed an average duty of about 18,000,000.

In 1798 the engine at Herland mine was found to do a much better duty than all the others in the county. It regularly performed 27,000,000. Watt paid a visit to the mine on purpose to examine it. He pronounced it perfect, and is reported to have declared that "further improvement could not be expected." [Taylor's *Records of Mining*, p. 154; Pole on the *Cornish Engine*, pp. 26-7; *Life of Trevithick*, by F. Trevithick, Vol. II., p. 83.]

The use of a higher pressure of steam, however, was subsequently adopted by the Cornish engineers with signal success. The enormous mass set in motion at each stroke of the engine served the purpose of a fly-wheel, to use Trevithick's comparison, and enabled a high rate of expansion to be applied. In 1820 an average of forty-five engines gave a duty of 28,700,000. In 1835 an average of fifty-one engines gave 48,210,293, while the best engine reported performed 91,672,211. More extraordinary still was the duty of an engine at Fowey Consols mine. After a patient and scrupulous investigation on the part of a number of scientific gentlemen, mine-managers, &c., on October 22nd and 23rd, 1834, the duty during the period of the trial was ascertained to be 125,000,000. [Lean's *Historical Statement*, pp. 97-100; Pole on the *Cornish Engine*, p. 65.]

The use of Hornblower's compound engine was revived by Arthur Woolf shortly after the expiration of Watt's patent, and many of his engines were erected in Cornwall; but on its being discovered that a similar economy could be obtained by working at a high rate of expansion with a single cylinder, Woolf's engine came to be abandoned.

Notwithstanding the great economy of the Cornish pumping engine, it has been comparatively little employed in the colliery districts. It

however, from this time ceased to play the important part it had hitherto performed in the history of the invention. The higher pressure of steam which began to be employed rendered its use of less consequence. In the case of the locomotive, and the high-pressure stationary engine, the condenser was entirely dispensed with, for the sake of simplicity, and portability, and of lessened first cost.

One of the first to promote the use of high-pressure non-condensing engines, as well as to bring the locomotive engine forward, was Richard Trevithick, of Camborne, Cornwall. Trevithick was born in the parish of Illogan, on the 13th of April, 1771. He was the son of a mine-manager, who bore the reputation of being one of the best informed and most skilful captains in the mines of the Camborne district.[1] Trevithick

is only within the last ten or twelve years that the first Cornish pumping engine in the North of England was erected by Mr. J. B. Simpson, who has since built several others. Of these the engine at Wallsend Colliery has a cylinder one hundred inches in diameter, that at Shiremoor Colliery an eighty-inch cylinder, at Hebburn Colliery a seventy-inch cylinder, besides two others, one at Wylam water-works, and the other at Stonecroft and Greyside lead mines.

Attention was drawn to the very great superiority of the Cornish pumping engine over those usually employed at the collieries in Scotland, in a short treatise published at Glasgow in 1861, by Mr. Ralph Moore, H.M. Inspector of Mines.—See *Papers on the Blackband Ironstones of Edinburgh and East Lothian Coalfield*, p. 17.

[1] *Life of Trevithick*, by F. Trevithick, London, 1872, Vol. I., p. 62.

was trained as an engineer,[1] and took an active part in the attempts to evade Watt's patent during the last few years of the eighteenth century. In 1797 he married a daughter of Mr. Harvey, of Hayle foundry. Their first residence was at Moreton House, near Redruth, within a stone's throw of Murdock's house, and but little further from Watt's residence at Plane-an-Guarry.[2] It is significant that from this time dates Trevithick's first attention to the high-pressure steam engine, and to the locomotive engine. His earliest models are stated to have been made and tried "about the year 1796 or 1797."[3] There is little doubt that he had become acquainted with the experiments made by Murdock about ten years earlier, which were only desisted from on account of the strong opposition of Watt. Mr. Davies Gilbert (at one time president of the Royal Society, and a friend and adviser of Trevithick) relates that on one occasion Trevithick came to him and inquired with great eagerness as to what he apprehended would be the loss of power in working an engine by the force of steam, raised to the pressure of several atmospheres,

[1] It has been frequently stated that Trevithick was a pupil of Murdock, but whether this was really the case the writer has been unable to discover. See Smiles's *Lives of the Engineers*—"George and Robert Stephenson," ed. 1874, p. 67; Tredgold on the *Steam Engine*, ed. 1851, Vol. II.—*History of the Steam Engine*, p. 47, note; *Life of Trevithick*, by F. Trevithick, London, 1872, Vol. I., p. 145.

[2] *Life of Trevithick*, by F. Trevethick, London, 1872, Vol. I., p. 64.

[3] *Ibid.* p. 103.

but instead of condensing to let the steam escape. "I of course," says Mr. Gilbert, "answered at once that the loss of power would be one atmosphere, diminished power by the saving of an air-pump with its friction, and in many cases with the raising of condensing water. I never saw a man more delighted, and I believe that within a month several puffers were in actual work." [1]

In the year 1800-1, immediately after the expiration of Watt's patent, we find Trevithick actively engaged in the introduction of his first high-pressure engines, and in the construction of a fire or steam carriage.[2]

The high-pressure engines were known as *puffers,* in contradistinction to the noiseless condensing engines. In Cornwall they were used for raising the ore and refuse from the mines. The cheapness and simplicity of the portable high-pressure engine caused it to come much into use.

Trevithick's first steam carriage was put together at a smith's shop in Camborne. On Christmas-eve, 1801, the steam was got up, and the engine started along the high road, with about seven or eight passengers, going off "like a little bird." It went half a mile up the Beacon hill, when something went wrong, and it was taken back to the smith's shop.

The next day it went to a place called Crane, about a mile off, that Captain Andrew Vivian's family, who

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[1] *Life of Trevithick,* by F. Trevithick, Vol. I., p. 63.

[2] *Ibid.* pp. 90, 106.

lived there, might see it. "Old Mrs. Paul cried out 'Good gracious, Mr. Vivian! what will be done next? I can't compare un to anything but a walking puffing devil.'"

They then started to go to Tehidy House, about two or three miles off, where Lord Dedunstanville lived. Trevithick took charge of the engine; his friend Vivian was steering. They were going very well around the wall of Rosewarne, when they came to a kind of open water-course across the road; the steering handle was jerked out of Vivian's hand, "and over she turned"

"The carriage," says Mr. Davies Gilbert, (who was at Tehidy House awaiting their arrival,) "was forced under some shelter, and the parties adjourned to the hotel, and comforted their hearts with a roast goose, and proper drinks, when, forgetful of the engine, its water boiled away, the iron became red hot, and nothing that was combustible remained either of the engine or house."[1]

Regarding the details of Trevithick's first steam carriage little information has been preserved. Horizontal bellows, worked by the engine, were used to urge the fire, but the steam could not be kept up for any length of time. The following account of it appeared in a contemporary Falmouth newspaper:—

"In addition to the many attempts that have been made to construct carriages to run without horses, a method has been

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[1] *Life of Trevithick*, by F. Trevithick, Vol. I., pp. 107-117.

lately tried at Camborne, in this county, that seems to promise success.

"A carriage has been constructed containing a small steam engine, the force of which was found sufficient, upon trial, to impel the carriage, containing several persons, amounting at least to a ton and a half weight, against a hill of considerable steepness, at the rate of four miles an hour; upon a level road it ran at the rate of eight or nine miles an hour. We have our information from an intelligent and respectable man who was in the carriage at the time, and who entertains a strong persuasion of the success of the project. The proprietors are now in London soliciting a patent to secure the property."[1]

On the 24th of March, 1802, Trevithick and Vivian obtained a patent[2] for improvements in steam engines, and their application to propelling carriages, &c. Mr. Davies Gilbert (then Giddy), who took a great interest in the infant locomotive engine, in a letter to the Rev. R. Polwhele, dated 1802, refers to it in the following terms:—

"Mr. Richard Trevithick has obtained a patent for moving carriages by steam. His machine consists of a fire-place, boiler, and cylinder, suspended near the centre of a waggon, from whence the power is transferred to the wheels by means of toothwork and cranks. If this contrivance answer the expectations of many persons well-informed on mechanical subjects, it will become of great national importance; and assisted by iron-railed roads may prove eminently useful to the mining district of Cornwall, where a sum little short of a thousand pounds a week is now paid for transporting copper-ore and coals to the sea-coast and the mines."[3]

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[1] *Life of Trevithick*, by F. Trevithick, Vol. I., p. 114. [2] No. 2599.

[3] Polwhele's *History of Cornwall*, Vol. IV., p. 137, note.

While in London on the business of the patent, Trevithick and Vivian were strongly recommended to get a carriage made for exhibition in London. They approved of the suggestion themselves.

Immediately after the patent was obtained the building of another carriage was proceeded with. It was to run from Camborne to Redruth some time in the spring of 1803. Crowds of people went to see the machine, which was popularly known as "Captain Trevithick's puffing devil." After running about a mile, in going up the Tuckingmill hill towards Redruth, the driving wheels slipped round and sank into the road, and the carriage stuck fast.[1] The idea of running between Camborne and Redruth had to be abandoned. The engine portion was afterwards sent to London, where a new passenger carriage was built for it.

The second engine had a cylinder five and a half inches in diameter, with a stroke of two and a half feet. With thirty pounds of steam it worked fifty strokes a minute. It was taken to London about the middle of 1803, and attached to the carriage at Felton's shop, in Leather Lane, where the carriage had been built.[2]

The streets of London presented fewer obstacles to the progress of the steam carriage than the rough

[1] *Life of Trevithick*, by F. Trevithick, Vol. I., p. 120.
[2] *Ibid.*, pp. 139-140.

roads of Cornwall. A number of journeys were made with the new machine (Fig. 40).[1] One or two trips were made in Tottenham Court Road, and in Euston Square. Captain John Vivian, a seafaring gentleman, has given the following account of a trial in which he took part:—

"One day they started about four o'clock in the morning, and went along Tottenham Court Road and the New Road, or City

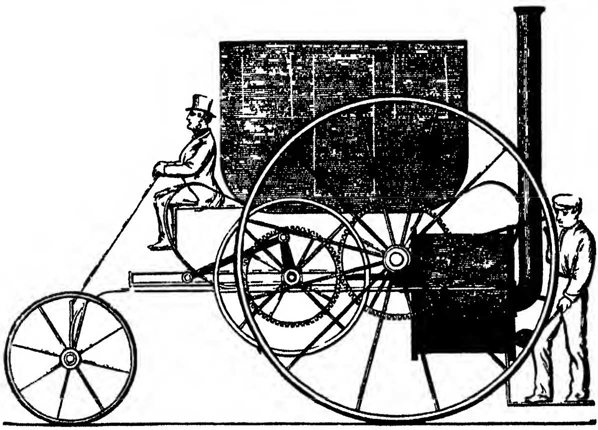

FIG. 40—TREVITHICK'S STEAM CARRIAGE, 1803

Road; there was a canal by the side of the road at one place, for he was thinking how deep it was if they should run into it. They kept going on for four or five miles, and sometimes at the rate of eight or nine miles an hour. I was steering, and Captain

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[1] This and the three following figures have been taken, by permission, from the full and interesting *Life of Trevithick*, written by his son the late F. Trevithick, and published by Messrs. E. and F. N. Spon.

Trevithick and some one else were attending to the engine. Captain Dick came alongside of me and said, 'She is going all right.' 'Yes,' said I, 'I think we had better go on to Cornwall.' She was going along five or six miles an hour, and Captain Dick called out 'Put the helm down, John!' and before I could tell what was up, Captain Dick's foot was upon the steering-wheel handle, and we were tearing down six or seven yards of railing from a garden-wall. A person put his head out from a window and called out, 'What the devil are you doing there? What the devil is that thing?'"[1]

The trials in London were brought to a close by the framing of the engine getting a twist. The carriage was sold for what it would bring. The engine portion was applied to drive a mill for rolling hoop-iron. Trevithick's attempts to introduce steam carriages, on common roads, ended with the experiments in London. West and Vivian, his partners in the enterprise, were disheartened by the failure.[2] Experience proved that after all Watt had acted wisely in refraining from attempting to apply the steam engine to road locomotion.

[1] *Life of Trevithick*, by F. Trevithick, Vol. I., p. 113.
[2] *Ibid.*, p. 145.

CHAPTER XVII.

THE LOCOMOTIVE ENGINE APPLIED ON RAILWAYS.

UP to this time we have no account of any steam locomotive having been tried upon a railway. In a letter to Mr. Davies Gilbert, dated August 22nd, 1802, Trevithick mentions that the Coalbrookdale Company had begun a carriage at their own cost for the railroads, and were forcing it with all expedition; [1] but we have no subsequent reference to it.

On the 1st of October, 1803, shortly after the termination of the trials in London, we find Trevithick at Pen-y-darran, in South Wales, engaged in the construction of high-pressure engines. A locomotive engine for the railroads was also in progress, and was expected to be ready in a fortnight.[2] It was several months, however, before it was completed, chiefly owing

[1] *Life of Trevithick*, by F. Trevithick, Vol. I., p. 155.
[2] *Ibid.*, Vol. II., p. 126.

to Trevithick's absence on other business. At length, early in the following year, he was able to communicate to Mr. Gilbert the results of the trials of the locomotive (Fig. 41) as follows :—

"February 15th, 1804.—Last Saturday we lighted the fire in the tram-waggon, and worked it without the wheels to try the engine. On Monday we put it on the tram-road. It worked

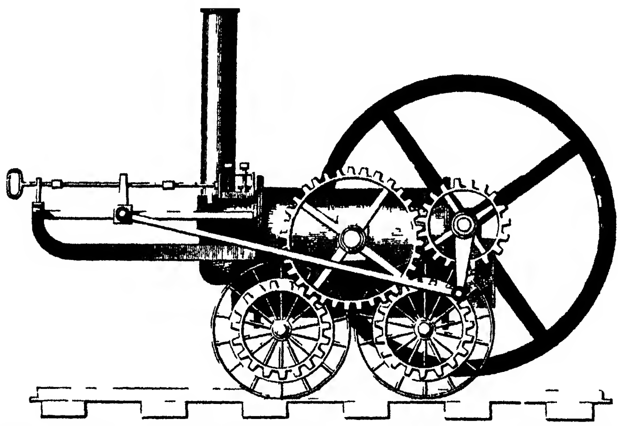

FIG 41.—TREVITHICK'S LOCOMOTIVE ENGINE AT PEN-Y-DARRAN, SOUTH WALES, 1804.

very well, and ran up hill and down with great ease, and was very manageable. We had plenty of steam and power.

"February 20th.—The tram-waggon has been at work several times. It works exceedingly well, and is much more manageable than horses. We have not tried to draw more than ten tons at a time, but I doubt not we could draw forty tons at a time very well; ten tons stands no chance at all with it. We

have been but two miles on the road and back again, and shall not go further till Mr. Homfray comes home.

". . . . The engine, with water included, is about five tons. It runs up the tram-road of two inches in a yard forty strokes per minute with the empty waggons. The engine moves forward nine feet at every stroke. The public are much taken up with it.

". . . . The steam that is discharged from the engine is turned up the chimney about three feet above the fire, and when the engine works forty strokes per minute, four and a half feet stroke, eight and a quarter inches diameter of cylinder, not the smallest particle of steam appears out of the top of the chimney, though it is but eight feet above where the steam is delivered into it, neither at a distance from it is steam or water found. I think it is made a fixed air by the heat of the chimney. The fire burns much better when the steam goes up the chimney than when the engine is idle. I intend to make a smaller engine for the road, as this has much more power than is wanted here. This engine is to work a hammer.

"February 22nd.—Yesterday we proceeded on our journey with the engine; we carried ten tons of iron, five waggons, and seventy men riding on them the whole of the journey. It is above nine miles, which we performed in four hours and five minutes. We had to cut down some trees and remove some large rocks out of the road. The engine, while working, went nearly five miles per hour; no water was put into the boiler from the time we started until we arrived at our journey's end. The coal consumed was two hundredweights. On our return home, about four miles from the shipping place of the iron, one of the small bolts that fastened the axle to the boiler broke, and all the water ran out of the boiler. which prevented the return of the engine until this evening. . . . We shall continue to work on the road, and shall take forty tons the next journey.

"March 4th.—We have tried the carriage with twenty-five tons of iron, and found we were more than a match for that weight. . . . The steam is delivered into the chimney above the

damper; when the damper is shut the steam makes its appearance at the top of the chimney; but when open none can be seen. It makes the draught much stronger by going up the chimney."[1]

We hear nothing more of the tram-engine, or *travelling-engine*, as Trevithick begins to call it, till July 5th, when we learn that it had made two more journeys to the shipping place, with a load of ten tons of iron each time, but had now been taken off the road and was employed in working a hammer.[2]

The weight of the engine broke many of the tram-plates, which were of cast iron. The hooks between the trams likewise frequently gave way. During the third journey to the basin, the engine went off the road and broke both axles. It was brought back to Pen-y-darran by horses, and converted into a stationary engine.[3]

Imperfect as this first railroad locomotive engine was, with its single cylinder and fly-wheel, it is obvious that its failure was attributable to the weakness and roughness of the tram-road rather than to defects in the engine itself.

Between July 5th and September 23rd, 1804, Trevithick paid a visit to Newcastle. As yet no locomotive engines had been tried in the North. It would appear that during this visit Trevithick had made some

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1 *Life of Trevithick*, by F. Trevithick, Vol. I., pp. 159-167.

2 *Ibid.*, Vol. II., p. 133. 3 *Ibid.*, Vol. I., pp. 174, 178.

arrangements relative to their introduction, as he speaks of going to Newcastle-on-Tyne in February, 1805, with the expectation of finding "some of the travelling engines at work." [1] Plans of the first Newcastle locomotive engine were lately, and probably are still, in existence. They comprised, "1. Well-executed perspective views of the engine from various points. 2. Drawings of waggon-engine, October 3rd, 1804. 3. Regulating and throttle cocks for engine, No. 1, September 17th, 1804." The engine was constructed at Mr. Whinfield's foundry, Gateshead; the engineer being one John Steel, who is stated to have worked at the making of the locomotive engine at Pen-y-darran. Whinfield was a sort of agent of Trevithick.[2]

It does not appear whether Trevithick paid his visit to Newcastle-on-Tyne in February, as contemplated, but in May, 1805, a locomotive engine had been completed. It was intended for Mr. Blackett of Wylam. The following curious notice of the engine may be seen in the Patent Museum at South Kensington:—

"Copy from R. W.'s memorandums on steam-engines. 'Memorandum, May 1st, 1805.—I saw an engine this day upon a new plan it is to draw three waggons of coals upon the wylam waggon way the road is nearly leavle the Engine is to travile with the waggons each waggon with the coals weighs about three-and-a-half tons and the Engine weighs four-and-a-half

[1] *Life of Trevithick*, by F. Trevithick, Vol. I., p. 173.

[2] *Ibid.*, Vol. I., pp. 183, 186, 187. *Mining Journal*, Saturday, Oct. 2nd, 1858.

tons the Engine is to work without a vacume.—The cylinder is seven inches diameter three feet stroke and is placed inside the Boilar and the fire is inside also the spead they Expect to travle at is four miles Per houre.

ROBT. WILSON.' "

A temporary railway is stated to have been laid down in the foundry-yard, "to let the quality see her run." There were several gentlemen present, and she ran backwards and forwards quite well. The engine, however, never left the works. For some cause Mr. Blackett did not take it, and it was converted into a stationary engine, and set to blow a cupola in the foundry.[1]

Trevithick's efforts to introduce his locomotive engine as a motive power on the railroads in South Wales and the North of England, had proved no more successful than his attempts to apply the steam carriage on common roads. For a few years from this time nothing more is heard of the locomôtive engine, Trevithick being engaged with other concerns, including an attempt to drive a tunnel under the bed of the river Thames. His connection with the Thames driftway ceased in the spring of 1808, and immediately afterwards we find him engaged in a novel enterprise with the locomotive. He resolved to establish a species of steam-circus in London; to construct a circular railway within an inclosure, and to exhibit a locomotive engine upon it; the public to be admitted to the inclosure at

[1] See another version in Nicholas Wood on *Railroads*, ed. 1831, p. 128-9.

a charge of a shilling each, including a ride in the carriage attached to the engine for those who were not too timid. The engine (Fig. 42) was named "Catch-me-who-can," at the suggestion of a sister of Mr. Davies Gilbert.

Regarding the progress of the enterprise Trevithick,

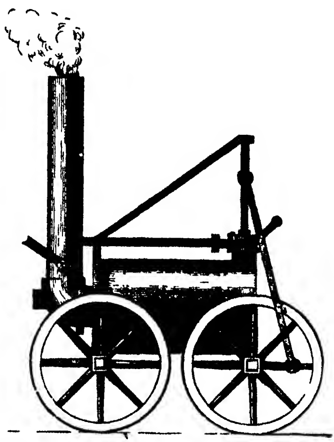

FIG. 42—TREVITHICK'S LOCOMOTIVE ENGINE, "CATCH-ME-WHO-CAN," 1808.

on the 28th of July, 1808, writes to Mr. Gilbert as follows:—

"I have yours of the 24th, and intend to put the inscription on the engine which you sent me.

"About four or five days ago I tried the engine, which worked exceedingly well, but the ground was very soft, and the engine (about eight tons) sunk the timbers under the rails and broke a great number of them. I have now taken up the whole of the

timber and iron, and have laid balk of from twelve to fourteen inches square down on the ground, and have nearly all the road laid again, which now appears very firm. We prove every part as we lay it down by running the engine over it by hand. I hope it will all be complete by the end of this week."[1]

The railway, which appears to have been about 100 feet in diameter (Fig. 43), was situated in a field adjoining the New Road, near or at the spot now forming the southern half of Euston Square. A gentleman who rode upon it, with his watch in his hand, declares that he went at the rate of twelve miles an hour, and that Trevithick then gave it as his opinion that the engine would go twenty miles an hour or more on a straight railway.[2] The cylinder of the engine was fourteen and a half inches in diameter, with a stroke of four feet.

After continuing in operation for some weeks, the "racing steam horse" enterprise was brought to an abrupt conclusion. A rail broke, the engine flew off at a tangent, and was overturned. The project had not proved a pecuniary success, and the engine was not again set upon the rails. This was the last of Trevithick's attempts to bring forward steam locomotion.

Notwithstanding the courage and ingenuity displayed by Trevithick, in connection with the introduction of the high-pressure steam engine, and the locomotive, his

[1] *Life of Trevithick*, by F. Trevithick, Vol. I., p. 192.

[2] The engine at Pen-y-darran had travelled without its load at a speed of sixteen miles an hour. *Ibid.*, Vol. II., p. 42.

impatience and impetuosity proved fatal alike to his fame and fortune. Many of the lessons which his experience had taught him had to be re-learnt by

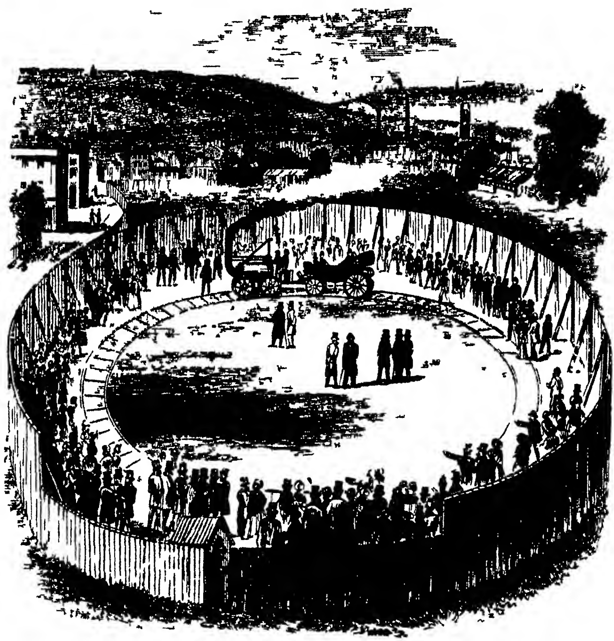

FIG. 45.—TREVITHICK'S CIRCULAR RAILWAY AT LONDON, 1808

subsequent inventors, who bore off the laurels which he might have earned. Even before the date of the expiration of his patent, the use of the locomotive engine

had become successfully established by others, who reaped the fruits of his unrecompensed exertions.

The earlier boilers employed by Trevithick usually consisted of cylinders of cast iron. The fire-place was situated in a wrought iron tube passing through the boiler from one end to the other. The internal tube in some cases was made to return again through the boiler, the chimney being placed at the same end of the boiler as the fire door. Subsequently he adopted cylindrical boilers made of *wrought iron* plates.

The pressure of steam used by Trevithick was very variable, sometimes as low as twenty pounds on the square inch, but on one occasion we find him pressing a boiler as high as 145 pounds. The danger of using highly elastic steam was not found to be so great as had been apprehended by Watt. On the occasion of the bursting of a boiler at Greenwich, in 1803, by which three persons were killed on the spot, and a fourth fatally injured, Boulton and Watt endeavoured to procure an Act of Parliament to put a stop to the use of high-pressure steam as dangerous to the public. Their efforts only led to an inquiry being made by Government engineers, as to the strength of the materials used in the construction of the high-pressure engines. The accident in 1803 was clearly traceable to neglect. The boy who had charge of the engine had gone to catch eels in the foundation of the building, leaving the care of it to a labourer. This

man, seeing the engine going much faster than usual, stopped it, without taking off a spanner which fastened down the steam-lever. The explosion followed a short time afterwards. The boiler in this case was of a globular form; it was six feet in diameter, and made of cast iron about one inch thick. It burst in all directions. One piece, weighing about five cwts., was thrown upwards of 125 yards. In consequence of this accident Trevithick determined to employ two steam-valves, and a steam-gauge, in future, and never again to let the fire come in contact with cast iron. The boiler had been heated red hot, and all the joints burnt, a few days before the explosion.[1]

Watt is stated to have declared that Trevithick "deserved hanging" for introducing the high-pressure steam engine;[2] but the force of public opinion went against him. The value of the machine was considered to more than outweigh any risk attached to its use.

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[1] *Life of Trevithick*, by F. Trevithick, Vol. II., p. 124-6, and Vol. I., p. 162.

[2] *Ibid.*, Vol. II., p. 395.

CHAPTER XVIII.

RENEWED ATTEMPTS TO EMPLOY LOCOMOTIVE ENGINES ON RAILWAYS.—ITS SUCCESSFUL ACCOMPLISHMENT.

THOUGH Mr. Blackett, of Wylam, had for some reason declined to take the locomotive engine made for him in 1805, he appears never to have abandoned the idea of ultimately adopting this means of haulage in lieu of horses on his waggonway. It was doubtless with this end in view that he reconstructed his railway about the year 1808, taking up the wooden rails previously employed, and replacing them by cast iron plate-rails, as we find him writing to Trevithick in 1809 on the subject of an engine. In his reply, Trevithick stated that he was engaged in other pursuits, and having declined the business, he could render no assistance.[1]

No further steps were taken by Mr. Blackett at the time, but the attention of others had also been directed

[1] *Who Invented the Locomotive?* by O. D. Hedley, published 1858; *Life of Trevithick*, by F. Trevithick, Vol. I., p. 196.

to the subject of steam locomotion. On the 10th of April, 1811, a patent[1] was granted to "John Blenkinsop, of Middleton, in the parish of Rothwell, in the county of York, coal viewer, for his invented certain mechanical means by which the conveyance of coals, minerals, and other articles, is facilitated, and the expense is rendered less than heretofore." The special object which Blenkinsop had in view was the conveyance of coals on the railway from Middleton Collieries to Leeds, a distance of about three and a half miles. The special feature of his invention consisted in the use of a *rack-rail* fixed in the centre of the railway, or forming part of the rails on one side. No form of locomotive engine is included in Blenkinsop's patent (Trevithick and Vivian's patent for the application of the high-pressure engine to propelling carriages being still in force), but the "steam engine" is mentioned as the motive power most suitable for the purpose. Blenkinsop employed the then celebrated firm of engineers, Messrs. Fenton, Murray, and Wood, of Leeds, to construct locomotive engines for him. At the suggestion of Mr. Murray, the leading spirit of the firm in engineering matters, each locomotive was provided with *two double-acting cylinders*,[2] now first employed in the locomotive engine.

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1 No. 3431.

2 *Locomotive Engineering*, &c., by Zerah Colburn, 1871, p. 15; Smiles's *Lives of the Engineers*—"George and Robert Stephenson," ed. 1874, p. 72.

This was a great improvement, a regular and steady action being obtainable from it without the use of a fly-wheel. The engine (Fig 44) was mounted on a frame of timber with smooth wheels, and drove a pinion working in the rack-rail, thus propelling itself and the load

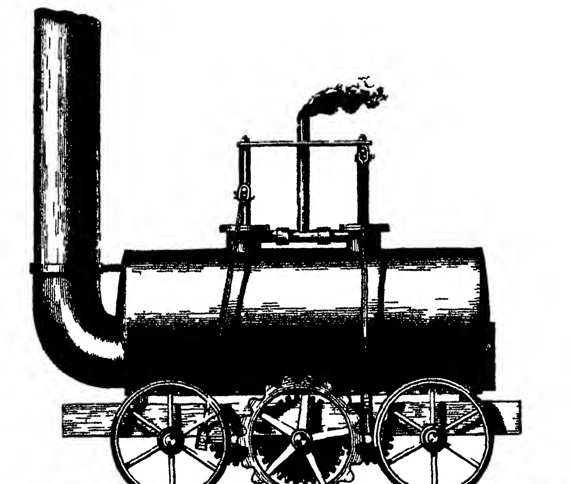

FIG 44 —BLENKINSOP'S LOCOMOTIVE ENGINE, 1812

attached to it The application of the rack enabled a comparatively light engine to haul a heavy train of waggons, and to ascend gradients which the smooth-wheeled locomotive used by Trevithick could not have surmounted.

As above remarked, Trevithick's patent was still in force, though, as we have seen, he had abandoned the project of steam locomotion himself. Whether the following allusion has reference to the introduction of Blenkinsop's engines, or some other engine, is not clear, but it seems to be the only trace of any connection between Trevithick and the Leeds firm. It occurs in a letter from West to Trevithick, dated September 7th, 1815, after the ill-success of the patent had led to a quarrel among the partners:—

"What right," says West, "have you to make me a debtor to you for 40*l.* received of Wood and Murray? I hold a copy of your answer to them, saying you held no share in the patent at that time when they wrote to you respecting the engine, but recommended them to W. West, whom you sold a share to, saying Wm. West would license to erect engines on the patent. . . . I never received a single sixpence from the patent before that from Messrs. Wood and Murray; then I made a present of 1*l.* to your children, because you refused making a charge for the drawing sent to Leeds."[1]

Blenkinsop's engines began running on the railway from Middleton Collieries to Leeds, on the 12th of August, 1812. They continued in use many years, and were the first instance of the regular employment of locomotive engines.

Regarding these engines and their performances, Blenkinsop stated that an engine with two eight-inch cylinders weighed five tons, and drew twenty-seven

[1] *Life of Trevithick*, by F. Trevithick, Vol. I., pp. 237-8.

waggons, weighing ninety-four tons, on a dead level, at three and a half miles per hour, or fifteen tons up an ascent of two inches in the yard; when lightly loaded it travelled at ten miles an hour; did the work of sixteen horses in twelve hours; and cost 400*l.*[1]

The success which attended the use of Blenkinsop's engines at Leeds gave a new impulse to steam locomo-

[1] Partington on the *Steam Engine*, 2nd ed., London, 1827, p. 43. Blenkinsop's engines continued in use in the neighbourhood of Leeds for many years. In a treatise entitled *Observations on a General Iron Rail-way*, [4th ed., London, 1823,] it is proposed to employ Blenkinsop's engines and rack rail, of which views are given. The author exhibits the utmost confidence in regard to the future of the locomotive engine. "In many parts of England," he says, "they have been long in use, but in Leeds more particularly are they improved; for this town is regularly supplied with coals, from pits several miles distant, by means of steam engines, without having any recourse to horse power. *Should my plan not be acted upon during this generation, the time is not remote when it, or something similar, will supersede all the present expensive conveyance in our inland departments;* of this I am thoroughly convinced by the great improvement in all arts and sciences, and the encouragement held out by government and the public in general, to promote such improvements," p. 46.

The pamphlet is published anonymously, but is stated to be from the pen of Thomas Gray, a native of Leeds. [*Railways, Steamers, and Telegraphs*, by George Dodd, 1868, p. 15.] The first edition of the pamphlet (published in 1820) we have not seen, but in the second edition, published in 1821, we find the author suggesting "the propriety of making the first essay between Manchester and Liverpool." He would thus appear to have been the earliest to propose the construction of this railway, as a locomotive line.

Blenkinsop's engines were still used on the Middleton Colliery railway in 1831. [Nicholas Wood on *Railroads*, ed. 1831, p. 128.]

tion. In the North of England especially, where a network of railways of considerable extent already existed between the numerous collieries and their respective "staiths" or shipping places, on the banks of the Tyne and Wear (Plate II.), much attention was immediately directed to the subject.

Several different methods of applying the steam engine to locomotive purposes were patented forthwith. Like Blenkinsop's patent, these all had reference to the means to be employed to enable the engine to pull or push itself forward, rather than to the form of the engine itself. The railways of this date, it is to be remembered, were very weak, the best being laid with rails of cast iron, but more commonly wooden rails were employed. It was therefore a *sine quâ non* that the locomotive should be made as light as possible, and it was doubtless this consideration, rather than any erroneous notions, that led the engineers of this period to make up for the want of weight in the engine by giving it a more powerful hold of the track.

Within less than a year after the introduction of Blenkinsop's engines, three different methods of effecting steam locomotion were patented by others. In order of time these stand as follows:—

On the 30th of December, 1812, a patent[1] was granted to "William Chapman, of Murton House, in the county of Durham, civil engineer, and Edward Walton Chapman,

[1] No. 3632.

of Willington Ropery, in the county of Northumberland, rope maker," for the use of a chain extending along the centre of the railway and secured at both ends. This chain was made to wind round, or pass over, a grooved wheel turned by the engine, so arranged that the wheel could not turn round without travelling along the chain. By this means the engine was designed to pull itself forward, together with the load attached to it.

On the 13th of March, 1813, a patent[1] was granted to "William Hedley, of Wylam, in the county of Northumberland, coal viewer," which included several methods of increasing the tractive power of the engine. In his specification, which is dated May 10th, 1813, Hedley observes as follows: "I make use of wheels for the carriage of cast iron or wood, by way of increasing the friction or adhesion between the wheels of the conducting carriage and railway; and when the rail is of cast iron, with a round or flat surface, I attach, or cause teeth or flanges to project from both sides of the wheels of the conducting carriage to enter the ground between the stones, sleepers, or rails, so as to prevent the whole from surging or turning on their own axis," &c.

It appears that Hedley had first turned his attention to the subject of steam locomotion in October, 1812,

[1] No. 3666.

at the request of Mr. Blackett.[1] The Wylam railway had, as we have seen, been laid with cast iron plate-rails only a short time before the invention of the rack-rail by Blenkinsop. To have adopted Blenkinsop's mode of haulage would have occasioned considerable outlay, independently of the patent royalty. Hedley, therefore, after satisfying himself of the feasibility of the plan by some preliminary experiments, resolved to make use of smooth wheels as Trevithick had done; and though both he and Trevithick included in their specifications means for increasing the tractive power in certain cases, we are not aware that either of them made use of this at any time.

On the 22nd of May, 1813, a patent[2] was granted to "William Brunton, of Butterley ironworks, in the parish of Pentrich, in the county of Derby, engineer, for his invented method and machinery for propelling or drawing carriages upon roads or railways, also boats, barges, or vessels, upon canals or navigations, by means of certain levers or legs, alternately or conjointly acting upon such roads, railways, canals, or navigations, or upon machinery attached thereto."

The many schemes which were on foot to effect locomotion by steam, caused the year 1813 to be a memorable one in the history of the locomotive engine. Three

1 *Who Invented the Locomotive?* by O. D. Hedley, p. 35; *Life of Trevithick*, by F. Trevithick, Vol. I., p. 202.

2 No. 3700.

locomotives, each acting on a different principle, were set to work upon three different colliery railways on the north side of the river Tyne—Messrs. Chapman's chain engine, on Heaton Colliery railway; Hedley's smooth-wheeled engine on Wylam Colliery railway; and one of Blenkinsop's engines on the Kenton and Coxlodge railway.

Regarding Messrs. Chapman's engine, it need only be remarked that the chain was found to give rise to great friction, and the engine to be very liable to get out of order, on which account it was soon abandoned.[1]

The first engine tried by Hedley on the Wylam railway, had a cast iron boiler, and a single cylinder with a fly-wheel. The fire-tube passed straight through the boiler to the chimney. The engine is stated to have been built by Thomas Waters, an ironfounder in Gateshead. It went badly, the obvious defect being want of steam. Another engine was then built in the workshops at Wylam. It had, like the first, a single cylinder and fly-wheel, but was provided with a boiler of wrought iron. The fire-tube, instead of passing straight through the boiler, was made to return; the chimney being placed at the same end of the boiler as the fire-place. This was found to be a great improvement. The engine was placed on four wheels and went well. A short time after it commenced, it regularly

[1] Dunn's *View of the Coal Trade of the North of England*, p. 53; Nicholas Wood on *Railroads*, ed. 1831, p. 130.

drew eight loaded coal waggons after it, at the rate of four or five miles an hour.[1] It was by the introduction and continued use of smooth-wheeled engines on the Wylam railway, that the absence of the necessity for any further aid than that supplied by the adhesion of the wheels to the rails was satisfactorily demonstrated. A locomotive which commenced to work on the Wylam railway at a very early period, and bore the name of "Puffing Billy," after a long career of public usefulness, has found a resting place in the Patent Museum at South Kensington."[2]

The event, however, which attracted most attention to steam locomotion in the North of England, during the year 1813, was the trial of one of Blenkinsop's engines on the Kenton and Coxlodge railway, on the

[1] *Who Invented the Locomotive Engine?* by O. D. Hedley, p. 35; *Life of Trevithick*, by F. Trevithick, Vol. I., pp. 202 3; Smiles's *Lives of the Engineers*—"George and Robert Stephenson," ed. 1874, pp. 75-76; Nicholas Wood on *Railroads*, ed. 1831, p. 134. In some accounts the second engine is stated to have been provided with two cylinders, but this appears to be an error.

[2] "Puffing Billy" is provided with two cylinders. It is asserted to have commenced working in 1813. In a letter on the "Wylam Dilly," signed J. Forster, which appeared in the *Newcastle Daily Chronicle*, 15th March, 1880, the year 1814 is stated to be the date when this two cylinder engine commenced working The latter date seems to the writer the more probable one. The Wylam locomotives were at one time placed upon eight wheels. See a drawing of one, given by Mr. Hedley to Partington, published in the frontispiece of the 2nd ed. of his account of the *Steam Engine*, and a description of the same at page 177.

2nd of September. These engines had already established a name for themselves at Leeds, where they had now been working upwards of a year. The great interest manifested in the trial will appear from the following notice of it, taken from the local papers of the time:—

"An ingenious and highly interesting experiment was performed in the presence of a vast concourse of spectators, on the railway leading from the collieries of Kenton and Coxlodge, near Newcastle, by the application of a steam-engine, constructed by Messrs. Fenton, Murray, and Wood, of Leeds, under the direction of Mr. John Blenkinsop, the patentee, for the purpose of drawing the coal-waggons. About one o'clock the new invention was set a-going, having attached to it sixteen chaldron waggons loaded with coals, each waggon with its contents weighing four tons or thereabouts, making altogether an aggregate weight little short of seventy tons. Upon perfectly level road, the machine so charged, it was computed would travel at the rate of three and a half miles per hour, but in the present instance its speed was short of that, owing, no doubt, to some partial ascents in the railway. Under all the circumstances, it was very highly approved of, and its complete success anticipated. After the experiment was finished, a large party of gentlemen connected with coal-mining partook of an excellent dinner provided at the Grand Stand for the occasion, when the afternoon was spent in the most agreeable and convivial manner." [1]

[1] Richardson's *Local Historian's Table Book*, Newcastle-upon-Tyne, 1843, Historical Division Vol. III., p. 127. Blenkinsop's locomotive appears not to have remained long in use on the Kenton and Coxlodge Railway, the gradients being probably too heavy for it.

Brunton's curious machine, which he termed a "Mechanical Traveller," was tried upon the railway at Crick lime-works, belonging to the Butterley Company. It is stated by the inventor to have performed very well. Its step was twenty-six inches long. With steam of a pressure of forty or forty-five pounds per square inch, it was propelled at the rate of two miles and a half per hour, and raised perpendicularly 812 lbs. at the same speed. It was intended to be set regularly to work.[1]

Another of Brunton's engines was fitted up at Newbottle Colliery in 1813, but this mode of haulage being found inconvenient and objectionable, its use was abandoned.[2]

The subject of steam locomotion had now been brought prominently before the owners and officials of the collieries in the North of England. Among those who took a lively interest in the matter was George Stephenson, who, together with his son Robert Stephenson, afterwards achieved so much celebrity in connection with the improvement of the locomotive, and the general introduction of railways. George Stephenson was born on the 9th of June, 1781, in a house situated on the north bank of the river Tyne, about half a mile to the east of the village of Wylam,

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[1] *Repertory of Arts*, Vol. XXIV., p. 65, *et seq.*

[2] Dunn's *View of the Coal Trade of the North of England*, p 53.

and in immediate proximity to the Wylam Colliery railway. He was brought up as a colliery engineman, and by his industry and ability had succeeded in improving his position step by step. At the date of the locomotive engine trials above referred to, Stephenson held the position of colliery engineer, or chief enginewright, at Killingworth and other collieries belonging to Lord Ravensworth and partners—a company known by the name of the "Grand Allies." The Killingworth railway was only one or two miles distant from the Kenton and Coxlodge and Heaton railways, and a few miles further from the Wylam railway.

The adoption of steam locomotion on the Killingworth railway having been sanctioned by the owners of the colliery, Stephenson set about the construction of an engine early in 1814.[1] Following the design of Blenkinsop's engine, he employed a cylindrical boiler of wrought iron, with an internal wrought iron fire-tube passing through it; two vertical cylinders of eight inches diameter and two feet stroke let into the boiler, with cross-heads and connecting-rods to work the propelling gear.[2] At this point, however, he took the opportunity to depart from Blenkinsop's plan. The regular working of the smooth-wheeled locomotive on the Wylam railway had shown that, on railways

[1] Nicholas Wood on *Railroads*, ed. 1831, p. 134.

[2] Smiles's *Lives of the Engineers*, "George and Robert Stephenson," ed. 1874, p. 82-3.

deviating but little from a dead level, the patent rack-rail with its corresponding pinion was not essential.[1] Stephenson accordingly decided to make use of smooth wheels.

Stephenson's engine was tried on the Killingworth railway on July 27th, 1814, upon a piece of road with edge-rails ascending about one in four hundred and fifty. It dragged after it, exclusive of its own weight, eight loaded carriages, weighing altogether thirty tons, at the rate of four miles an hour, and after that time continued to work regularly.[2]

For a considerable number of years few improvements of much note were effected in the locomotive. The spur-gearing, which was employed in Hedley's and Blenkinsop's engines, as well as in Stephenson's first engine, was soon abandoned by the latter for the simpler arrangement of attaching the connecting-rods directly to the driving-wheels — an improvement which was patented by Dodds and Stephenson on the 28th of February, 1815[3] (Fig. 45). Springs too were applied by Stephenson at the suggestion of Mr. Nicholas Wood.[4] But even as late as the year 1827 the fate of the locomotive engine still hung in the

[1] Nicholas Wood on *Railroads*, ed. 1831, pp. 129, 132, 133.

[2] *Ibid.*, ed. 1831, p. 136.

[3] No. 3887.

[4] In 1816, Stephenson, in conjunction with Mr. Losh, patented an arrangement of steam piston springs, but this being found open to numerous objections, was soon abandoned in favour of steel springs.

balance. Of five locomotives supplied by Stephenson, in 1822, to work on the Hetton Colliery railway, three had been laid aside in favour of fixed engines; and in a *Report* on the colliery made in 1827, it was recom-

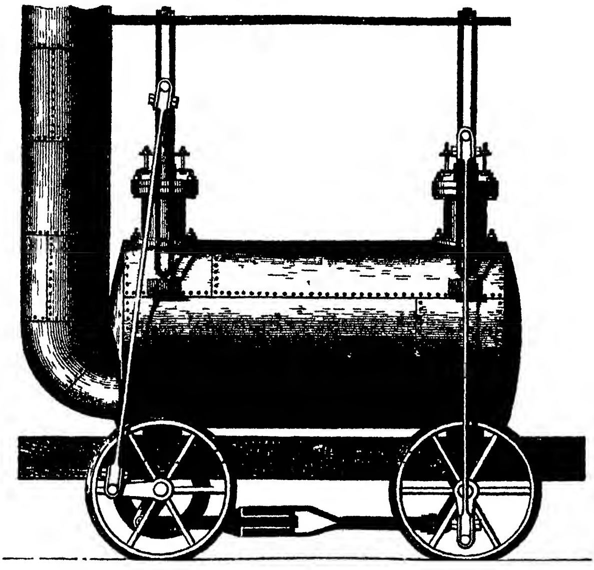

FIG. 45—GEORGE STEPHENSON'S LOCOMOTIVE ENGINE, 1815.

mended as "well worthy of consideration whether it would not be advisable to substitute reciprocating engines" in place of the two remaining locomotives.[1] On the Stockton and Darlington railway locomotives

[1] These two locomotives drew sixteen waggons each, and worked a portion of the railway one and a quarter miles in length.

continued to be used, but "the principal haulage of the line was performed by horses." The working of the locomotive engines appears not to have been regarded with any degree of satisfaction, and it is stated to have been under consideration in 1827, whether horses should not be alone employed, to the exclusion of locomotive engines.[1] As yet locomotion by steam had not achieved much success; an efficient form of engine remained to be invented.[2]

At this juncture, Timothy Hackworth, a highly ingenious mechanic, who occupied the position of manager of the working department of the Stockton and Darlington railway, introduced some important modifications in an engine which he designed, whereby the power and compactness of the smooth-wheeled locomotive were much advanced.[3] Departing from the then usual plan of having two upright cylinders working on *different* shafts, Hackworth inverted his cylinders, and,

[1] *History of the Steam Engine*, by Robert Scott Burn, 2nd ed. p 114.

[2] At this period the locomotive engine was as unpopular in the North of England as it was inefficient. In the Act of Parliament for making the Newcastle and Carlisle railway, which received the Royal Assent on May 22nd, 1829, it was expressly provided that "no locomotive or moveable steam engine shall be used on the railway for drawing waggons or other carriages, or for any other purpose whatsoever."

[3] The boiler of the engine was taken from a locomotive which had been supplied to the Stockton and Darlington railway by Wilson of Newcastle-on-Tyne. As originally constructed it had four cylinders, two to each pair of wheels, and appears to have been the first engine in which the power from two pistons was applied to a single pair

placing them on opposite sides of the boiler, applied their connecting-rods to actuate *the same axle-tree.* At the same time he adopted the *return fire-tube* which was used by Trevithick and Hedley, in lieu of the straight flue employed in Blenkinsop's and Stephenson's engines; and by throwing the escaping steam into the chimney through a narrow orifice, he greatly augmented the force of the *steam-blast*, and consequently the rapidity of combustion in the furnace.[1]

The engine in which the above improved arrangements were first combined was built by Hackworth in 1827, and named the "Royal George" (Fig. 46). It was the first of a new type, and the nearest approach to

of wheels. [Zerah Colburn on *Locomotive Engineering, &c.*, p. 21.] How the four cylinders were placed we are not informed, but it is obvious that the arrangement was inefficient, from the fact of its being so soon abandoned.

[1] Hackworth was a native of Wylam, and took part in the building of "Puffing Billy." He was one of the most ingenious of the pioneers of locomotive engineering. [For an account of him, see *The Practical Mechanic's Journal*, Vol. III., p. 49, 1850-51—"A chapter in the History of Railway Locomotion," and memoir, p 225 of same volume.]

There has been considerable controversy regarding the invention of the steam-blast which is so essential a feature of the locomotive engine. The improved combustion arising from turning the waste steam into the chimney was well known to Trevithick and Mr. Davies Gilbert, the latter having written a letter on the subject to *Nicholson's Journal* in 1805. We have the testimony of Mr. Nicholas Wood, however, that "it was afterwards laid aside or only partially used, when only slow rates of speed were required," until revived by Mr. Hackworth, "in a more forcible manner than before used, throwing it up as a jet," &c. [Treatise on *Railroads*, ed. 1831, p. 390.]

the modern locomotive of any engine that had yet been built.

From this time the clumsy overhead gearing formerly employed disappeared in all the newer engines, the power being transmitted more directly and efficiently to the driving wheels.

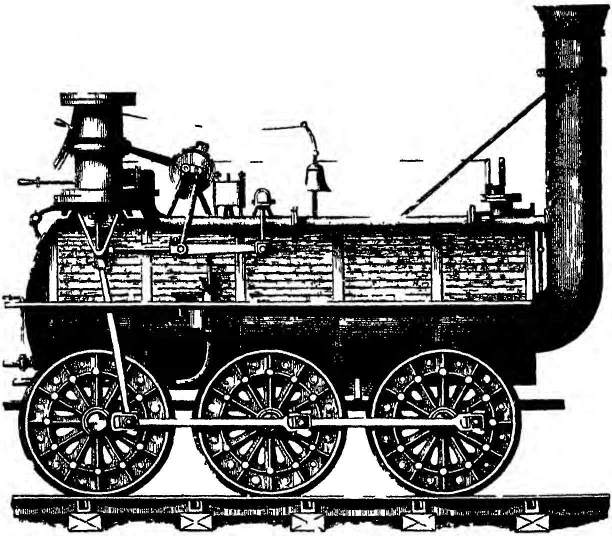

FIG. 46.—HACKWORTH'S LOCOMOTIVE ENGINE, THE "ROYAL GEORGE," 1827.

Improved arrangements similar to Hackworth's were adopted by Robert Stephenson in the "Rocket" (Fig. 47), built, in 1829, to compete in the celebrated trial of locomotives on the Liverpool and Manchester railway

which took place in the month of October in this year.[1] In this engine another notable feature was introduced, viz the *multitubular boiler*, then used in the

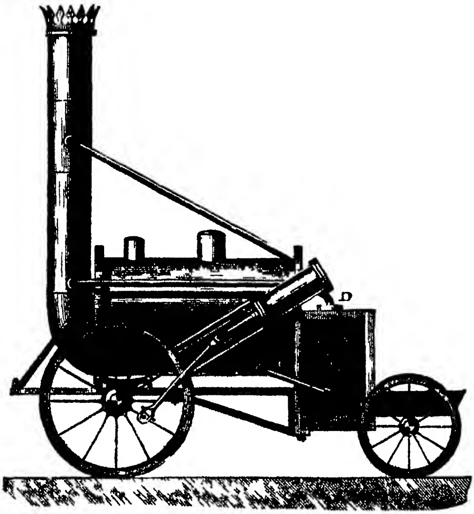

FIG 47 —ROBERT STEPHENSON'S LOCOMOTIVE ENGINE THE "ROCKET" 1829
A the boiler 6 feet long 3 feet 4 inches in diameter B the fire box enclosed in a casing 3 inches wide, containing water C, a water pipe communicating between the casing and the boiler D, a steam pipe between the same E, two pipes (one from each cylinder) for throwing the exhaust steam into the chimney

locomotive engine for the first time in England,[2] and applied in the "Rocket" at the suggestion of Mr

[1] *The Northern Year Book for* 1829, Newcastle, 1830, p 270

[2] The multitubular boiler was patented in France in 1828, by M. Seguin, engineer of the St Etienne railway, and was applied by him early in the following year to a locomotive engine which had been obtained from George Stephenson [Zerah Colburn on *Locomotive Engineering, &c* , 1871, p 23.

Booth, the secretary of the Liverpool and Manchester railway.[1] This proved an innovation of the greatest importance. The "Rocket" was the only engine which fulfilled the stipulated conditions of the trial at Rainhill—the two other principal competing engines, the "Sanspareil"[2] of Timothy Hackworth, and the "Novelty" of Messrs. Braithwaite and Ericsson, having both broken down during the trial. The prize of 500*l.* was accordingly awarded to the "Rocket," Mr. Booth obtaining a share of it, as he informs us in his treatise.[3]

By means of the multitubular boiler and the improved blast-pipe arrangement, steam could now be generated with great rapidity and economy in the locomotive, enabling a higher rate of speed and power to be attained than had previously been thought of. In connection with the competition at Rainhill, the subject of locomotives and railways, and their capabilities, was

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[1] Nicholas Wood on *Railroads*, ed. 1831, p. 387. Booth's *Account of the Liverpool and Manchester Railway*, 2nd ed. 1831, p. 75.

[2] The "Sanspareil" was built after the model of the "Royal George." Its steam-blast was so powerful as to cause a waste of fuel by the discharge of cinders out of the chimney. [Nicholas Wood on *Railroads*, ed. 1831, p. 390.]

[3] Smiles's *Lives of the Engineers*—"George and Robert Stephenson," ed. 1874, p. 218. Booth's *Account of the Liverpool and Manchester Railway*, 2nd ed. p. 77. The "Rocket" was subsequently considerably improved. It is now to be seen beside "Puffing Billy" in the Patent Museum at South Kensington. The high angle at which the cylinders were at first placed (viz. 45°) was found to give rise to a slight working of the boiler up and down on the springs, on which account they were afterwards brought to a nearly horizontal position.

brought into public notice in a more prominent manner, as well as in a more favourable light, than it had ever been before.[1]

The success which attended the use of steam locomotion on the Liverpool and Manchester railway inaugurated the modern railway system, which has brought about such marvellous changes during the last half century.

[1] In the account of the competition at Rainhill, published by Mr. Smiles in his *Life of George Stephenson* [ed. 1857, pp. 290-296], the elder and younger Stephenson appear to be referred to indifferently under the common name of "Mr. Stephenson." The result of this arrangement is that *George* Stephenson is made to figure as the hero of the contest. In the contemporary accounts, however, there is no such ambiguity of language, and in these it is *Robert* Stephenson, and not George, who plays the prominent part. [See *The Northern Year-Book* for 1829, pp 270-273; *The Mechanics' Magazine* (October and November, 1829), Vol. XII; *A Practical Treatise on Rail-Roads*, &c., by Nicholas Wood, 2nd ed. 1831, p. 363 *et seq.* - See also *Address on the two late eminent Engineers, the Messrs. Stephenson*, by Nicholas Wood, Newcastle-on-Tyne, 1860.]

CHAPTER XIX.

EARLY DAYS OF STEAM NAVIGATION.

The era of steam navigation, like that of steam locomotion, dates, as already stated, from the expiration of Watt's patent. Here little difficulty was experienced from the first. Watt's engine in its most perfect form could be employed without alteration. A smooth and level way was supplied by nature.

Experiments on steam navigation were resumed on the Forth and Clyde canal, in the year 1801. Mr. William Symington, who had acted previously as engineer to Mr. Miller, was now employed by Lord Dundas, the governor of the Canal Company, to construct a steam boat for towing vessels on the canal. After considerable preparation a boat, named the "Charlotte Dundas" (Fig. 48), after a daughter of Lord Dundas, was at length completed. It was fitted with a steam engine having a cylinder twenty-two inches in diameter, and placed in a nearly horizontal position. A

single paddle-wheel was used, fixed in the middle of the boat towards the stern. In March, 1802, an experiment was made in the presence of Lord Dundas and a number of gentlemen, when the steam boat took in tow two loaded sloops of seventy tons burthen each, and carried them a distance of nineteen miles and a half, in six hours, against a head wind.

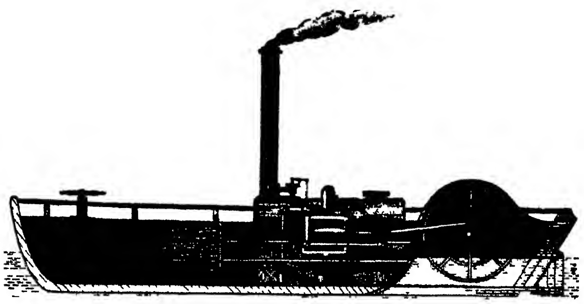

FIG. 48.—THE "CHARLOTTE DUNDAS," 1802.

Though the performance of the steam boat was entirely successful, an altogether extraneous cause prevented the project of employing steam tow-boats on the canal from being carried out. It was feared that the agitation of the water, occasioned by the action of the paddle-wheel, would injure the banks of the canal, and on this account the committee of management determined to abandon the scheme.[1]

[1] *Historical Account of the Steam Engine*, by James Cleland, Glasgow, 1825, p. 49.

The Duke of Bridgewater had been so satisfied with the success of Symington's boat as to give him an order for eight similar boats for his canal, but on the same day that Symington received notice of the adverse decision of the Forth and Clyde Navigation, he also received intelligence of the death of the Duke of Bridgewater.[1]

For some years no further attempts were made towards the introduction of steam navigation in Great Britain. Among those who took an interest in the matter, however, was Robert Fulton, an American by birth, who spent some time in Europe in the end of the last and the beginning of the present century. In 1802, he is stated to have visited, inspected, and tried Symington's steam boat, and to have noted down particulars of its machinery.[2] He also about the same time wrote to James Watt, jun., on the subject of a small engine.

"The object of my investigation," he states, "is to find whether it is possible to apply the engine to working boats up our long rivers in America. The persons who have made such attempts have commenced by what they called improving Watt's engine, but without having an idea of the physics which lay hid in it from common observers; but such improvements have appeared to me like the improvements of the preceptor of Alcibiades, who

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[1] Woodcroft, *On Steam Navigation*, 1848, p. 55. Muirhead's *Life of Watt*, 2nd ed., p. 425.

[2] *Historical Account of the Steam Engine*, by James Cleland, Glasgow, 1825, pp. 53-55.

corrected Homer for the use of his scholars. Their ill-success and their never having found a good mode of taking a purchase on the water are the reasons why they have all failed. Having, during the course of my experiments on submersive navigation, found an excellent mode of taking a purchase on the water, I wish to apply the engine to the movement. The only thing which is wanting is to arrange the engine as light and compact as possible," &c.[1]

Some steam-boat experiments were made by Fulton on the river Seine in 1803, and on the 6th of August in this year he ordered an engine from Soho, intended for a larger vessel to be built in America. The diameter of the cylinder was twenty-four inches, with a stroke of four feet. The principal parts of the engine were made and forwarded early in 1805. The vessel, the paddle machinery, and the subordinate parts of the engine, were designed and executed by Fulton himself.[2] The vessel, which was named the "Clermont" (Fig. 49), was launched in the spring of 1807. It was 133 feet long, eighteen feet wide, and nine feet deep. Shortly after being fitted with its machinery, it made a trip from New York to Albany, running the distance of 150 miles in thirty-two hours, and returning in thirty hours. In September, 1807, it was advertised as a regular passenger boat between New York and Albany.[3] The

[1] Muirhead's *Life of Watt*, 2nd ed., p. 426.

[2] *Ibid.*, pp. 426, 427.

[3] *A History of the Growth of the Steam Engine*, by Robert H. Thurston, 2nd ed., London, 1879, pp. 257, 260.

success of the "Clermont" led to the building of other and larger steamers soon afterwards, and from this time steam navigation was fairly established in America.

As yet there were no steam boats in use in Europe, but in the year 1811, Henry Bell, who at an early period had obtained information for Fulton regarding the experiments of Mr. Miller of Dalswinton, and had furnished him with drawings of machinery, resolved to

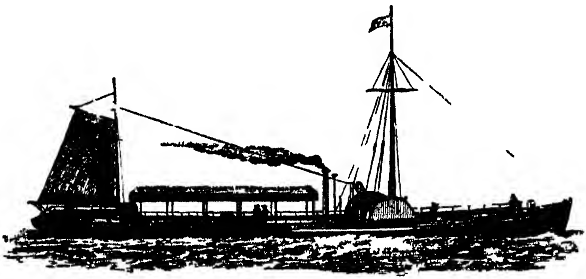

FIG. 49.—THE "CLERMONT," 1807

engage in the enterprise of starting a steam boat on the Clyde at his own risk. The building of his boat was commenced in October, 1811, and it was launched in June, 1812. It was named the "Comet" (Fig. 50), and was employed as a passenger boat on the Clyde between Glasgow and Greenock. It was forty feet long, ten feet wide, and twenty four tons burthen. It was about four horse-power.[1]

[1] *Memorials of James Watt*, by George Williamson, Esq., published by the Watt Club, 1856, p. 228 *et seq.* Muirhead's *Life of Watt*, 2nd ed., p. 428.

The "Comet" was soon followed by other steam boats on the Clyde. In 1813 the "Glasgow" was built, seventy-four tons and sixteen horse-power; in 1814, the "Morning Star," 100 tons and twenty-six horse-power; and in 1815, the "Caledonia," 102 tons and thirty-six horse-power. In this year two steam boats sailed from the Clyde to the Thames, one going

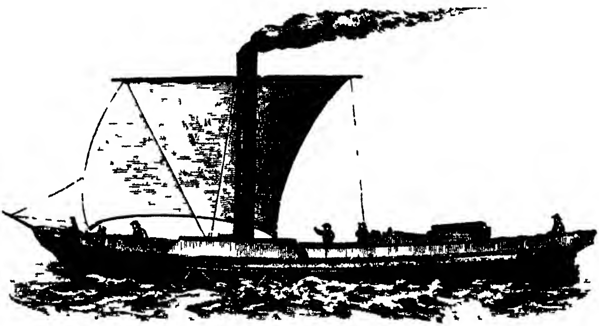

FIG. 50.—THE "COMET," 1812.

by the way of the Forth and Clyde Canal and the east coast; the other round the Land's End.

The "Caledonia," was purchased early in 1817 by James Watt, jun., and fitted with two new engines from Soho, of fourteen horse-power each, and in October of that year she performed the first voyage made by a steam boat from Great Britain to the Continent, running from Margate to Holland at an average speed of seven knots and a half an hour.[1]

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[1] Muirhead's *Life of Watt*, 2nd ed., pp. 429, 430.

From these small beginnings of comparatively recent date have gradually been developed the fleets of magnificent steam ships of the present day, which plough their way over all parts of the ocean, regardless alike of winds and calms, urged forward by the constant and untiring energy of the Steam Engine.[1]

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[1] The steam engine having been intimately connected in its early days with the mining interest of Great Britain, the effect of its later improvements in enabling the miners to penetrate to greater depths may not be unworthy of note.

The following table exhibits the rapid advance downwards during the present century:—

	1800	1820-30	1830-40	1840-50	1850-60	1860-70	1870-80
	Fas	Fas	Fas	Fas	Fas	Fas	Fas
Tin and copper mines	170 [1]	250 [2]	300 [3]	—	352 [4]	—	—
Coal mines	140 [5]	180 [6]	267 [7]	287 [8]	362 [9]	408 [10]	468 [11]

A century ago it was considered a great performance to land a load of six cwts. of coal from a depth of 100 fas. in two minutes. A colliery might be instanced where, from a depth of 200 fas., a load of forty-eight cwts. of coal is now landed in fifty-three seconds.

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[1] Crenver and Oatfield; [2] Dolcoath; [3] Consolidated Mines; [4] Tresavean; [5] Thwaite Pit, Whitehaven; [6] Gosforth, Newcastle-on-Tyne; [7] and [8] Monkwearmouth; [9] Apendale, Newcastle-under-Lyne; [10] Rosebridge, Wigan; [11] Pendleton, Manchester.

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